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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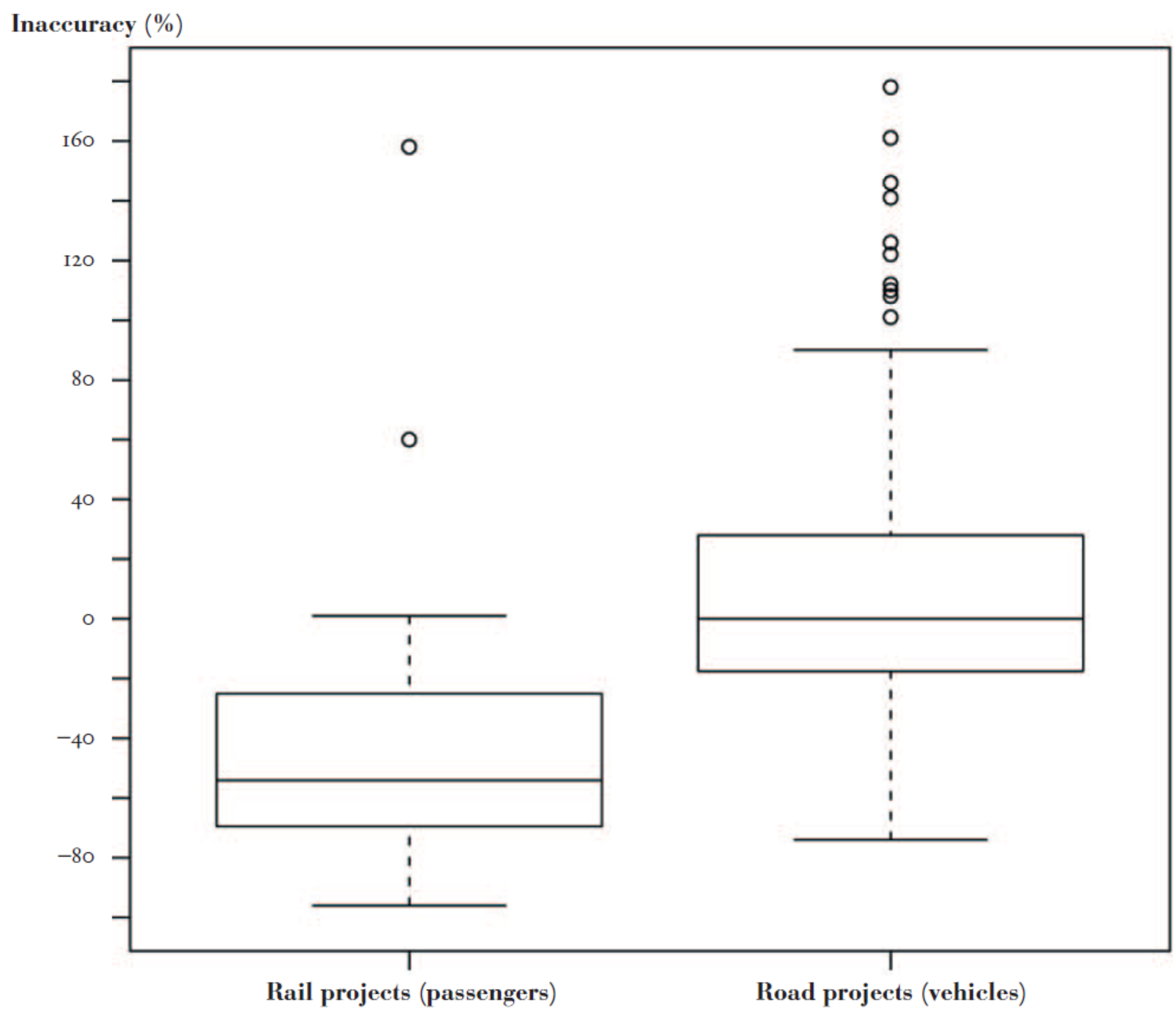

Overview of presentation

- 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)

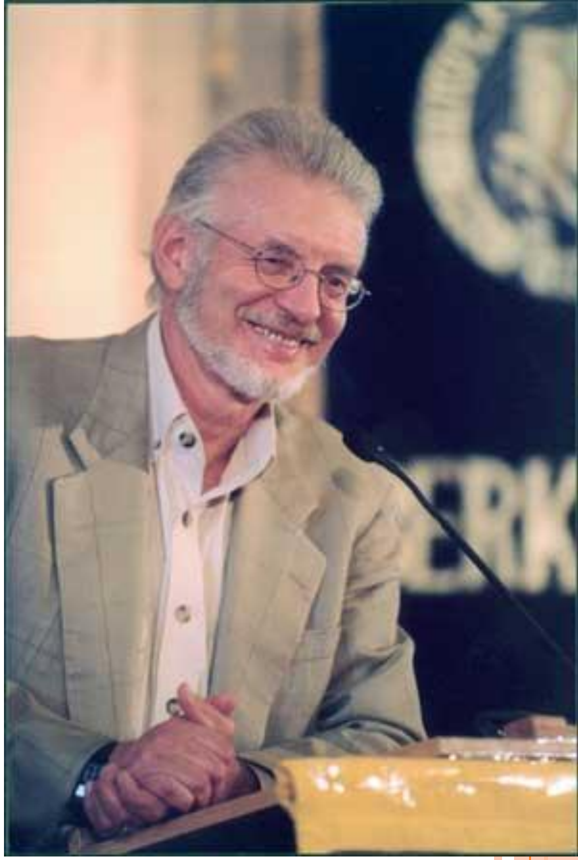
Europe has public transport!

- *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

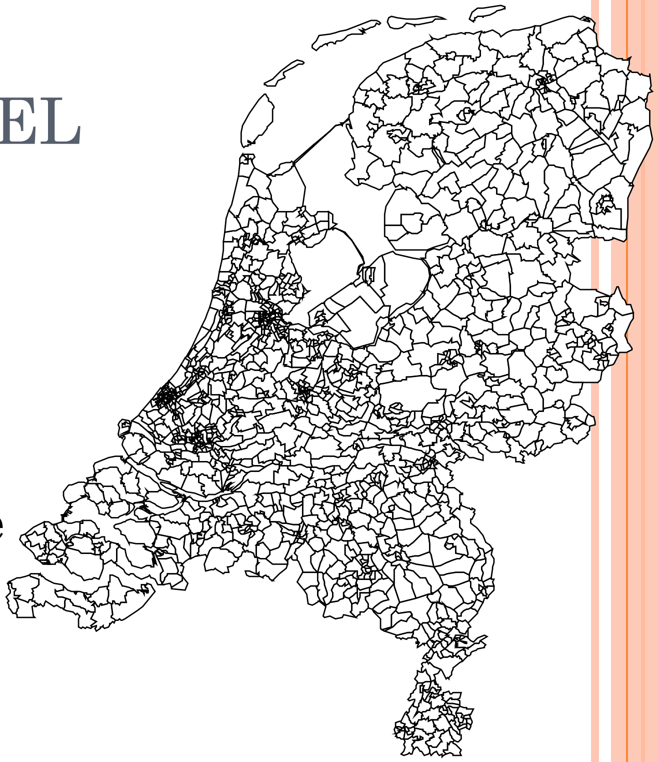
- reliance on physical analogy was viewed negatively
  - by economists, psychologists, (some) geographers …
- sophisticated mathematical models appealed strongly to a small minority
  - and further discouraged the majority
- work of Miyagi and of Anas showed the duality of entropy and utility theory
- 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



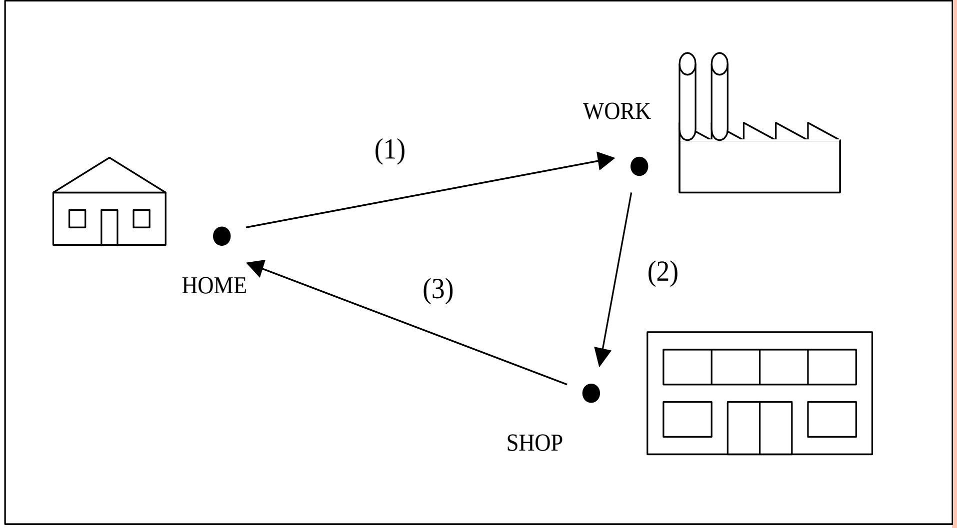
- large-scale model:
  - 500-3000 zones
  - multiple modes including walk & cycle
  - 4 or 5 stages modelled together
  - based on tours and detours
    - many aspects of activity-based models
  - assignment to networks with congestion
- major modelling investment with pay-off over a long period
  - 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

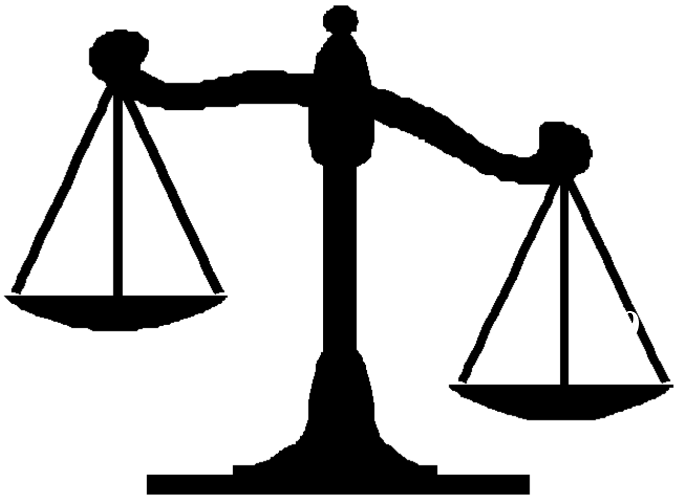
  emissions, local & global

  includes (e.g.) noise, particulates and CO_2

  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

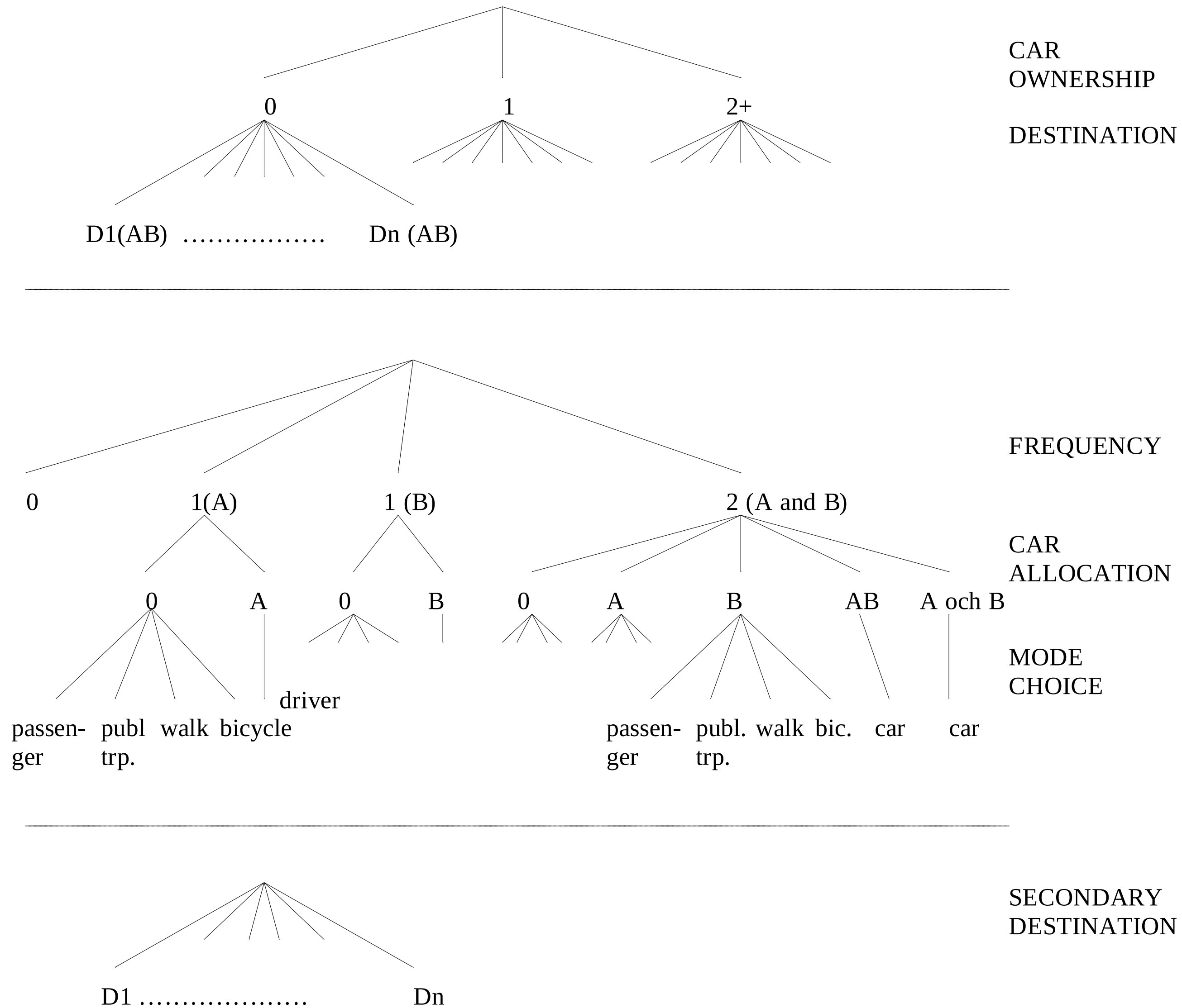
- giving effectively a simultaneous choice over all behavioural aspects
  - achieved by using nested logit models
  - with simultaneous estimation over as many aspects as possible
  - currently tree-nested models, but should be extending to cross-nesting in near future
  - and to more general model forms 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

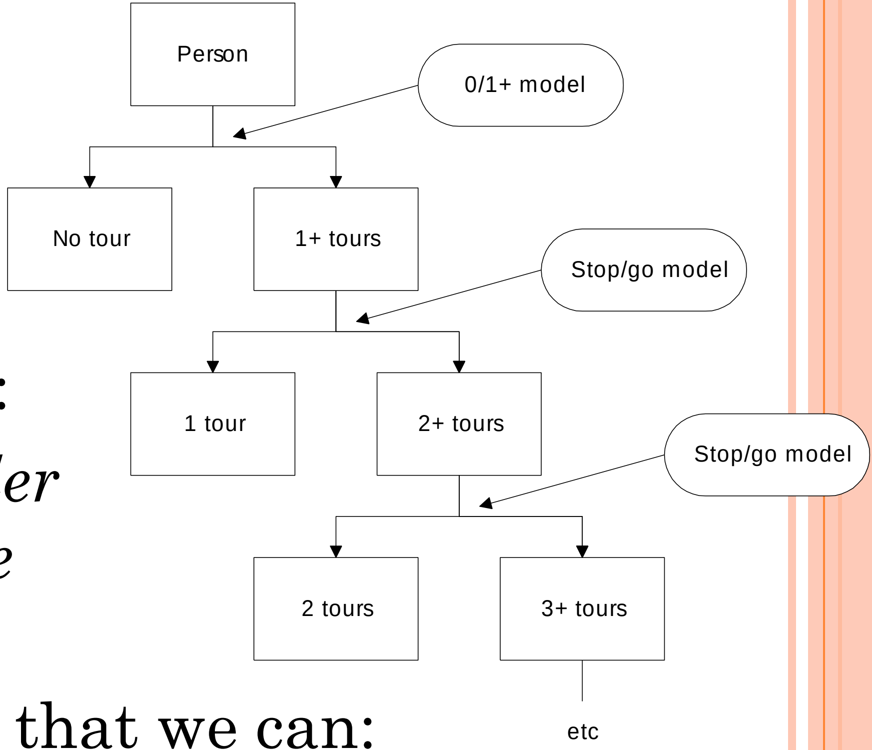
- park-and-ride as a sub-mode
- choice of toll roads
- inclusion of car ownership (and licence holding)
  - car type if required
- public transport pass ownership
- train type or route choice
- etc.

- this is all made possible by the explicit utility basis of the models

Complex systems of choices can be modelled



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.(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

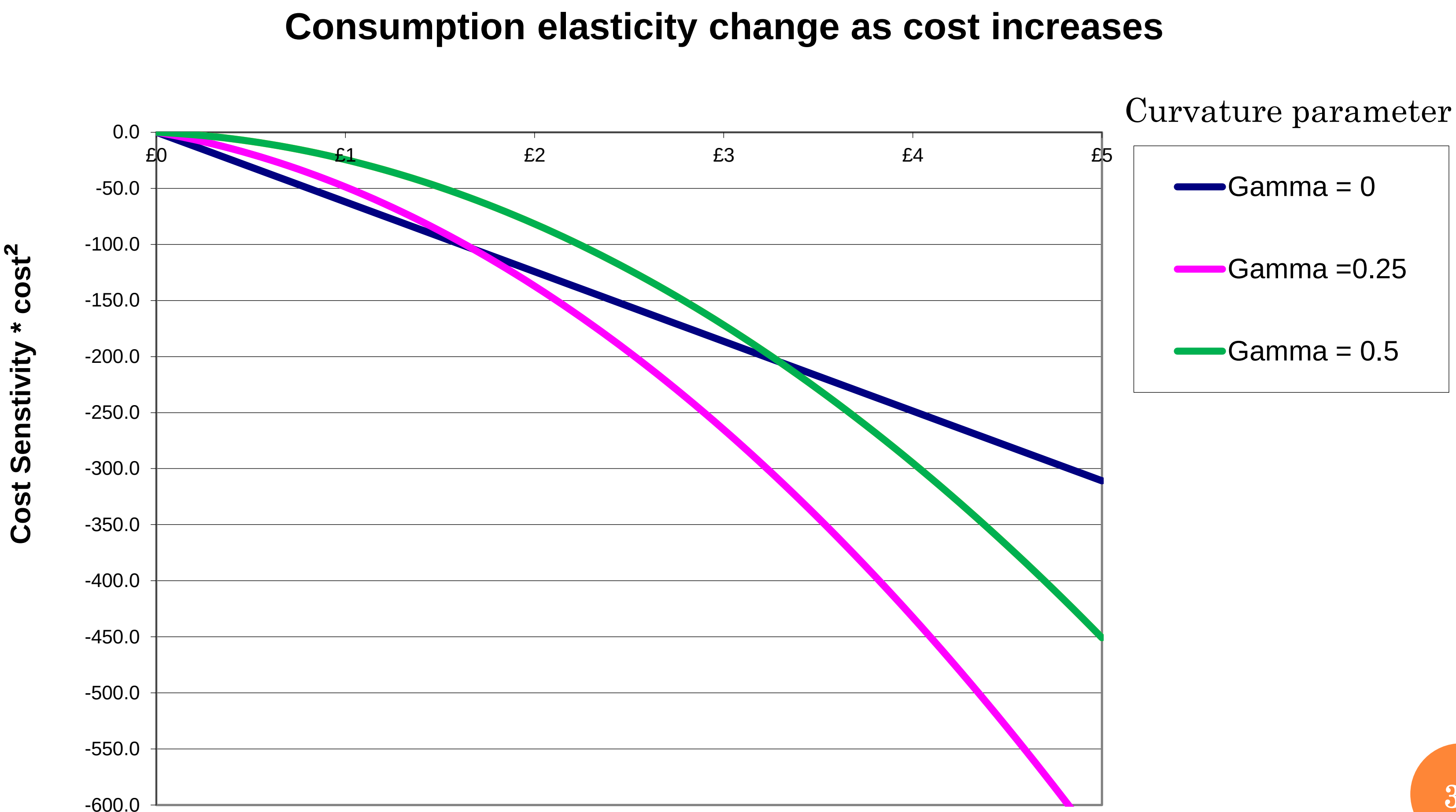
Elasticity is a useful test of performance

- 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



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

$$\boldsymbol{P} = \boldsymbol{B}.\frac{\boldsymbol{S_f}}{\boldsymbol{S_b}} \quad \text{and} \quad \boldsymbol{P} = \boldsymbol{B} + \left(\boldsymbol{S_f} - \boldsymbol{S_b}\right)$$

- 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:

$$E(Q_j) = \sum_k w_k \,.\, p_j(x_k)$$

- 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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