



Department  
for Transport

# **Econometric Models to Estimate Demand Elasticities for the National Air Passenger Demand Model**

March 2022

Department for Transport  
Great Minster House  
33 Horseferry Road  
London SW1P 4DR



© Crown copyright 2022

This publication is licensed under the terms of the Open Government Licence v3.0 except where otherwise stated. To view this licence, visit <https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/> or contact, The National Archives at [www.nationalarchives.gov.uk/contact-us](http://www.nationalarchives.gov.uk/contact-us).

Where we have identified any third-party copyright information you will need to obtain permission from the copyright holders concerned.

This publication is also available on our website at [www.gov.uk/government/organisations/department-for-transport](http://www.gov.uk/government/organisations/department-for-transport)

Any enquiries regarding this publication should be sent to us at [www.gov.uk/government/organisations/department-for-transport](http://www.gov.uk/government/organisations/department-for-transport)

# Contents

1. Introduction	4
Purpose of econometric analysis	4
Reasons for this update	5
Changes to econometric models	5
2. Econometric Analysis	7
Econometric model framework	7
Data	9
Model specification	11
Modelling diagnosis	14
Results of estimation and diagnosis	15
Missing markets and adjustments	19
Technical peer review	21
3. Results of econometric models	22
Long run air fare and income elasticities	22
Updated econometric models and output	24
Annex A: Peer Review of the Econometric Analysis	50

# 1. Introduction

## Purpose of econometric analysis

- 1.1 The department develops and runs an aviation model which produces forecasts at airport level out to 2050. The aviation modelling suite was described in detail when a full set of forecasts was last published in 2017.<sup>i</sup>
- 1.2 The primary focus of this document is on the redevelopment and recalibration of the long run elasticities, in particular the estimations relating to the income/economic activity elasticities of demand and the price/air fare elasticities. These elasticities will then feed into the initial unconstrained demand forecasting element of the modelling suite.
- 1.3 Unconstrained demand forecasts at a national level are estimated by the National Air Passenger Demand Model (NAPDM). These forecasts are driven by the demand elasticities estimated from econometric models. The objective of this report is to provide a technical update on the econometric models which underlie NAPDM and the aviation model suite.
- 1.4 The NAPDM forecasts feed into other components of the aviation model suite, notably the National Air Passenger Allocation Model (NAPAM). NAPAM allocates the passenger trip demand forecast by the NAPDM to individual airports. In doing so, NAPAM reflects airport capacity constraints (which, as well as affecting the distribution of demand across airports, might also reduce national demand). For the international-international transfer market, NAPAM also reflects competition from four overseas hubs. As such, the NAPDM operates unconstrained and needs no data on airports or future capacity constraints. However, it should be noted that the impact of capacity constraints is likely to be felt in air fares which do feed into the econometric modelling. More details on the NAPDM, how it fits into the modelling suite, and the updated definition of markets are available in Chapter 2 of Jet Zero: modelling framework.
- 1.5 For the purpose of NAPDM and this econometric analysis, each market is given a code of up to six letters, where the first letter indicates passenger residency ('U' for UK resident; 'F' for foreign passengers), the second letter indicates journey purpose ('B' for business; 'L' for leisure), and the rest of the letters refer to geographic regions ('D' for UK domestic; 'SE' for Southern Europe, 'RoE' for Rest of Europe; 'OECD' for

rest of OECD; and 'RoW' for Rest of the World). For example, FLSE relates to the market for foreign residents travelling for leisure to and from Southern Europe.

## Reasons for this update

- 1.6 Previous versions of the model used econometric models estimated using data up to 2008. Details of the approach undertaken then was set out in a technical report published by the department in 2011.<sup>ii</sup> The purpose of this update is to update the evidence base, using data up to and including 2017. This project used a similar technical approach to the previous exercise, albeit with a greater emphasis on the key issue of cointegration.
- 1.7 As last time, in some cases and where appropriate, we have undergone an exercise of adjustments to the elasticities derived from the econometric approach for use in forecasting. There are two primary reasons for this:
  - there are reasons to believe some elasticity estimates (particularly those relating to fares) are biased in some way, potentially due to data issues;
  - in the past we have assumed long run income elasticities decline over time through a process described as market maturity. We are likely to continue to make assumptions of this kind going forward. However, consideration of this issue is out of scope of this document.

## Changes to econometric models

We have updated the models to estimate the demand elasticities. The update has taken account of recent academic guidance on best practice and has gone through both internal peer review and an external academic review process. The key updates are listed below.

- The measure of demand for elasticities has changed from terminal passengers to trips. The difference between the two relates to the way passengers are counted – a passenger who transfers at a UK airport will be counted as three terminal passengers (once for each use of an airport runway) each way for just one trip. The need to transfer is best handled by the allocation model (NAPAM), so it is preferable to instead work in trips.
- The grouping of countries into international markets has changed. The previous (2011) models grouped countries into four regions: Western Europe (which in practice encompassed all of Europe including Russia), OECD, Newly Industrialised Countries (NIC) and Less Developed Countries (LDC). In contrast, the current model has moved to new four global regions: Southern Europe (SE), Rest of Europe (RoE), Rest of OECD (OECD) and Rest of the World (RoW).
- The input data were updated. 2011 models used data up to 2008, while the current models used the data up to 2017. The data include aviation traffic, income measures (e.g. GDP, import and export), and air fares.
- The current models included structural breaks, where applicable, and derived demand elasticities separately before and after the structural breaks. Although the previous 2011 models have tested structural breaks, no evidence was found, potentially because of short time series.

- Some explanatory variables have changed. In particular, the 2011 models included the exchange rate to US dollar as a driver only in the foreign leisure to OECD (FLOECD) market, while the current models included exchange rate to sterling pound in more markets, due to improved significance.

## 2. Econometric Analysis

### Econometric model framework

- 2.1 We used unrestricted error correction models (UECMs) to estimate the econometric regressions and resulting elasticities. This section sets out the framework and why we chose this approach.
- 2.2 To estimate an econometric model using time series data it is necessary to consider the properties of the data and the relationships between them. This is discussed at length in the literature – see for example, Enders (2004)<sup>iii</sup> and Giles (2012)<sup>iv</sup>.
- 2.3 Many economic data series are not stationary<sup>1</sup>; in other words, they are not  $I(0)$ . There is a risk that regressing two data series (in levels) that are  $I(1)$ <sup>2</sup> against each other would produce spurious results. To illustrate this concept, Hendry (1980)<sup>v</sup> reported that cumulative rainfall could be “shown” as determining the price level in the UK.
- 2.4 If a long run equilibrium relationship (in levels) between the variables exists this is known as cointegration. Cointegration means that although there may be temporary deviations from equilibrium, the equilibrium relationship will eventually be restored. If  $I(1)$  data are not cointegrated then the data should be differenced to make them  $I(0)$ , allowing conventional econometric techniques to be used.
- 2.5 Error correction models, unrestricted or otherwise<sup>3</sup>, can only be used if (a) the data are  $I(0)$  or  $I(1)$ , and (b) the data are cointegrated. As such, it is important to test that these conditions hold. If the data are cointegrated it is inappropriate to regress only first differences as the model will have serial correlation due to mis-specified dynamics.
- 2.6 Unrestricted error correction models (UECMs) have the advantage of providing both short run and long run elasticities. Although the primary focus of this project is on long run elasticities, controlling for the short run effects can materially affect the

---

<sup>1</sup> A stationary time series is one whose statistical properties such as mean, variance, autocorrelation, etc. are all constant over time.

<sup>2</sup>  $I(1)$  is a series that if differenced once becomes stationary. Similarly, an  $I(2)$  series becomes  $I(1)$  if differenced once, and  $I(0)$  if differenced twice.

<sup>3</sup> Unrestricted error correction models are also called conditional error correction models.

estimate of the long run elasticities because they are often very different in magnitude. Because of this, UECMs are often used for estimating models to be used for forecasting purposes.

2.7 In practice, most models took the form:

- $y_t = \gamma \Delta x_{1,t-1} + \delta \Delta x_{2,t-1} + \dots + \theta_0 y_{t-1} + \theta_1 x_{1,t-1} + \theta_2 x_{2,t-1} + \dots + e_t$  ; (1)
- All variables are in natural logarithms
- $y_t$ : traffic in time  $t$
- $x_{1,t}$ : first explanatory variable in time  $t$  ( $x_{2,t}$  represents the second explanatory variable and so on)
- $\gamma / \delta$ : short run coefficients to be estimated
- $\theta$ : long run coefficients to be estimated
- $e_t$ : residual at time  $t$

2.8 For some models a more complex functional form was used:<sup>vi</sup>

- $\Delta y_t = \sum \beta_i \Delta y_{t-i} + \sum \gamma_j \Delta x_{1,t-j} + \sum \delta_k \Delta x_{2,t-k} + \dots + \theta_0 y_{t-1} + \theta_1 x_{1,t-1} + \theta_2 x_{2,t-1} + \dots + e_t$  ; (2)
- All variables are in natural logarithms
- $y_t$ : traffic in time  $t$
- $x_{1,t}$ : first explanatory variable in time  $t$  ( $x_{2,t}$  represents the second explanatory variable and so on)
- $\gamma / \delta$ : short run coefficients to be estimated
- $\beta$ : short run coefficients to be estimated
- $\theta$ : long run coefficients to be estimated
- $e_t$ : residual at time  $t$

2.9 This model can be estimated using Ordinary Least Squares (OLS). The coefficients on the change in explanatory variables – in (1) and (2),  $\gamma$  and  $\delta$  – predict the short run impact of changes in the explanatory variables, predicting temporary deviations from the equilibrium. The speed at which demand is predicted to return to equilibrium, following either by deviations in the short run variables or random variation, is determined by  $\theta_0$ , and, if used,  $\beta_i$ .

2.10 For stability we require  $-2 < \theta_0 < 0$ . If  $\theta_0 = 0$ , then equilibrium is never restored, meaning cointegration does not exist. If  $-2 < \theta_0 < -1$  then the equilibrium is overshoot in the next period, with equilibrium gradually restored following oscillations. We would normally expect  $-1 < \theta_0 < 0$ , which means equilibrium is restored over time without overshooting. The closer  $\theta_0$  is to  $-1$ , the faster equilibrium is reached.

2.11 The long run relationships are determined by the  $\theta$  terms - the long run elasticity of variable  $x_1$  is equal to:  $-\theta_1 / \theta_0$ . . A demonstration of this is provided in Figure A1 of UK aviation forecasts (DfT, 2013).<sup>vii</sup> The use of the model is strongly geared towards long run forecasts, and so it is the long run elasticities that are of most interest.

2.12 In terms of the calculation of the confidence interval associated with each long run variable, we calculated this using the delta method. The confidence intervals of the long run variables for the preferred models are shown in Chapter 3.



- 2.13 Equations (1) and (2) do not include an intercept term. Such a term was tested for each model but was not found to be statistically significant. For most models lagged terms were not used for the short run effects (that is,  $i$ ,  $j$  and  $k$  were usually zero), although for some models some short run variables (and/or the traffic term) required a lag to avoid autocorrelation.
- 2.14 Attempts at estimating this model were made for each of the 16 international and two domestic markets, each of which had their own estimated coefficients.
- 2.15 UECMs also have the advantage of lending themselves to bounds testing, a powerful technique used to test for cointegration.
- 2.16 A downside to using UECMs is that each variable added results in the loss of at least two degrees of freedom – at least one to estimate the short run impacts, and one for the long run. Given we have only 32 years of data / observations (at least one of which does not fully feature in the regression because of the need for lags), this is a material consideration. However, we judge that we have enough observations to permit this approach to be used.

## Data

2.17 The data used for econometric analysis can be split into three components:

- passenger traffic
- aviation fares
- other international and UK explanatory variable data

For each dataset we have collected data from 1986-2017 for international markets and from 1991-2018 for domestic markets.

## Passenger traffic

2.18 Passenger traffic data were taken from three primary sources:

1. the CAA airport statistics ('CAA airport stats'), which were used for domestic markets and from 1996 for international markets.
2. the CAA passenger interview survey ('CAA survey') used for domestic markets and from 1996 for international markets. This was used to derive estimates of the journey purpose mix of passengers, and their residency (UK / foreign).
3. the International Passenger Survey ('IPS') used from 1986-1996 for international markets. This was used for the same purposes as the CAA passenger survey. It also provided information on total passenger traffic for this period.

2.19 The datasets were combined to produce a demand matrix for passenger trips from the main UK Airports with an ultimate origin or destination in the UK, disaggregated by year, region of destination, journey purpose and residency (UK or overseas).

## Fares data

- 2.20 The raw fares data came from the IPS for international markets, and from the CAA passenger survey for domestic markets, so they were based on reported passenger fares. Only data from direct trips were used. This is because any air fare which involves a transfer is problematic because we are unclear on whether the fare response applies to one or all legs (in the case of self-interlining where a passenger would need to buy two tickets). We also filtered out records where the airline is of type charter; this is because charter flights are often bought as part of a package holiday, and so the fare may reflect a bundle of products.
- 2.21 One caveat should be emphasised. The fares data relates to the (reported) actual fare by passenger; as such, it does not include the price of other ‘products’ which may have been included in the bundle, such as food, drink and checked baggage. There has been a trend over the past 30 years to unbundle these, particularly in the short haul market where food, drink and checked baggage are provided only for an additional charge. This trend means it is likely that our dataset exaggerates the fall in air fares over time, which would bias the magnitude of the estimated elasticity downwards. Furthermore, because the fare data is imperfect, there may be attenuation bias to the estimated price elasticities.
- 2.22 These biases are likely to be stronger for short haul, where the extent of unbundling has been greater than for long haul. This hypothesis is supported by the finding that the magnitude of the estimated price elasticity is higher if a long haul fare variable is used for the short haul market.
- 2.23 No data from foreign residents in the IPS was used as there are numerous difficulties in processing this; for example, the currency of the fare is often unclear. Instead, the index from UK residents was applied, adjusted for the different traffic mix. Again, this risks attenuation bias.
- 2.24 The fares indices were calculated using a Fisher index. The International Labour Office Handbook on consumer price indices supports this approach. Weighted fares were calculated at country level first (on a per passenger-km basis) before being aggregated to global regions and turned into an index. The fare indices were disaggregated by year, region of destination, journey purpose and residency (UK or overseas).

## Other explanatory variable data

- 2.25 Table 1 below sets out the explanatory variables used in the econometric models and their source.

Description	Source
UK consumption	ONS
UK GDP	ONS
Foreign market GDP	United Nations
Average of UK and foreign market GDP	Calculation (average of indices relating to UK GDP and foreign market GDP)
Imports	Previous econometric project (pre-1996), and HMRC (post-1996)

Exports	Previous econometric project (pre-1996), and HMRC (post-1996)
Trade	Calculation (average of indices relating to imports and exports)
Exchange rates	United Nations
Rail cost and time indices	DfT

**Table 1: Sources of other explanatory variable data**

- 2.26 For each variable we weighted its growth by the appropriate traffic mix for the year in question. For rail indices used as an explanatory variable for domestic markets, each rail origin-destination pair is mapped to an airport-airport flow, even when the rail flow is not between two airports. For example, London Bridge to Inverkeithing is mapped as Heathrow to Edinburgh.
- 2.27 There were numerous countries for which we did not have a complete data series for, particularly those in the former Soviet Union and former Yugoslavia. In such cases, the calculation of the relevant indices excluded these countries. Traffic to such countries form a small part of the relevant global region, and so we have no reason to believe these omissions are material.
- 2.28 Exchange rates for some countries, mainly small ones in the Rest of the World region, were volatile. However, there was little traffic associated with such countries. So, these countries were excluded from the calculation of the exchange rate variable. An increase in the exchange rate index represents a strengthening of the pound against the relevant basket of currencies.

## Model specification

### Functional form

- 2.29 We took the natural logarithm of all non-dummy data, meaning the resulting specification is of log-log form. This is a standard approach used in econometric models of this kind (including the DfT 2011 model). It makes interpretation relatively simple.

### Explanatory variables

- 2.30 Among the potential set of explanatory variables, we tried removing the variable with the t-statistic closest to zero one at a time, but this proved problematic. Often a variable was rejected early in the process, but then when tested later was found to be significant. Thus, the order of removal of variables was having a highly distortionary impact on the results. This is likely because the starting model had very few degrees of freedom and so was not reliable. Instead, numerous combinations of models were tested, focused primarily on a variety of income terms, fares and exchange rates.
- 2.31 Therefore, we selected the preferred model specification for each market by the following criteria:

- data of I(0) or I(1)
- passed the cointegration test
- passed the diagnostic tests
- credible and statistically significant long run elasticities
- robustness to the in/exclusion of specific dummy years
- no more complexity than necessary

2.32 Where possible long run variables were retained only when statistically significant, although when there was a strong a priori expectation that certain variables should be relevant – for example, air fares – then insignificant variables were in some cases retained so long as their coefficients had the intuitive sign. Short run variables were tested for only when the long run counterparts were included. Such variables were retained so long as they were of the intuitive sign – statistical significance was not required since, if their long run equivalents were relevant, then we may expect there to be a short run impact even if smaller.

2.33 Because of multi-collinearity it was generally impractical to include more than one income variable at a time, although occasionally a trade term was included alongside GDP. We therefore subjected each potential model to one potentially relevant income term.

### Annual dummies

2.34 We have tried to be parsimonious in our use of dummy variables. Where possible, we have used them only when there is a specific a priori reason for doing so, not merely when they are statistically significant. That said, these have been partially informed by plotting the residuals.

2.35 When a yearly dummy variable is used the UECM model implicitly assumes the effect is temporary and the equilibrium relationship (which does not change) is restored gradually through the lagged dependent variable – see equation (1). We may expect the path back to equilibrium to differ – given the cause of the divergence was not explained by the model – and so we also tested a dummy variable for the subsequent year as well. This was retained only if statistically significant.

2.36 This resulted in the following annual dummies being tested:

Year	Rationale
1990 and 1991 (Rest of World region only)	Political instability in China
1993 and 1994	Questionable traffic data
2001 and 2002	9/11 terrorist attack in 2001
2010 and 2011	2010 eruptions of Eyjafjallajökull

2.37 In practice, no more than four annual dummies were used in any one model. Where annual dummies were used, we tested the models without them to understand their impact.

2.38 Dummy variables which have a persistent effect had also been considered as set out in the Structural breaks section.

## Structural breaks

2.39 We considered two types of structural break:

- demand spikes upwards or downwards in a year and doesn't return to the previous trend, although the relationship between the drivers are unchanged after this point; and/or
- the long run relationship between drivers and traffic changes after a certain year.

2.40 The first of these was implemented through a dummy variable which takes a value of one after the year of the structural break, and zero otherwise. Taking ULOECD as an example: in the case of a structural break in 2000, the variable is called dPOST2000 (d represents dummy, and POST2000 represents years later than 2000). We formulated the model as:

$$\Delta \text{ULOECD.trat}_t = \beta_1 \Delta \text{ULOECD.AVEGDP}_t + \beta_2 \Delta \text{ULOECD.EXR}_t + \beta_3 \Delta \text{ULOECD.FARE}_t + \theta_1 \text{ULOECD.AVEGDP}_{t-1} + \theta_2 \text{ULOECD.EXR}_{t-1} + \theta_3 \text{ULOECD.FARE}_{t-1} + \theta_0 \text{ULOECD.trat}_{t-1} + \delta_1 d1994 + \delta_2 d2010 + \delta_3 d\text{POST2000} + e_t ; (3)$$

2.41 The variables d1994 and d2010 are annual dummies and are not related to structural breaks. In addition, because of the existence of the lagged level of traffic term combined with the fact that dPOST2000 does not change in value after the year 2000, the equilibrium rate of growth is not affected by dPOST2000, although the equilibrium level of traffic is.

2.42 The second type of structural break is more complex. To illustrate this, we take the same ULOECD market as an example and test the possibility that the GDP elasticity differs post-2000. To do so, we created a new variable, dPOST2000XULOECD.AVEGDP, an interaction term of dPOST2000 and ULOECD.AVEGDP. This variable represents the change in the log of GDP from the year 2000 onwards. Equation (3) was thus changed to :

$$\Delta \text{ULOECD.trat}_t = \beta_1 \Delta \text{ULOECD.AVEGDP}_t + \beta_2 \Delta \text{ULOECD.EXR}_t + \beta_3 \Delta \text{ULOECD.FARE}_t + \theta_1 \text{ULOECD.AVEGDP}_{t-1} + \theta_2 \text{ULOECD.EXR}_{t-1} + \theta_3 \text{ULOECD.FARE}_{t-1} + \theta_0 \text{ULOECD.trat}_{t-1} +$$

$$\theta_4 d\text{POST2000XULOECD.AVEGDP}_{t-1} + \delta_1 d1994 + \delta_2 d2010 + \delta_3 d\text{POST2000} + e_t ; (4)$$

2.43 This new variable does change the equilibrium rate of growth since the variable changes over time. The long run elasticity of GDP with respect to traffic is  $-\theta_1 / \theta_0$  prior to the year 2001, and  $-\{(\theta_1 + \theta_4) / \theta_0\}$  from 2001 onwards.

## Lag structure

2.44 Because (a) the data are annual and (b) adding a lagged short run variable results in the loss of two degrees of freedom, we included additional lags only if necessary. We first estimated a model with no lags on the short run variables and the necessary one lag on the long run level variables. Once a credible model was estimated, we tested the impact of adding a lag to the short run variables for each variable in turn. If there

was an issue with autocorrelation, we additionally tested the impact of including a lagged difference in traffic, and retained any which solve the autocorrelation issue.

## Modelling diagnosis

### Cointegration tests

2.45 The UECM can be used only if the data are cointegrated. As such the cointegration test is an important step of the process. We used the bounds testing approach to test the cointegration, set out by Pesaran and Shin (1999)<sup>viii</sup> and Pesaran et al. (2001)<sup>ix</sup>. As described in Giles (2013)<sup>x</sup>, this has significant advantages:

- It can be used with a mixture of  $I(0)$  and  $I(1)$  data.
- It involves just a single-equation set-up, making it simple to implement and interpret.
- Different variables can be assigned different lag-lengths as they enter the model.

2.46 The first and last of the above are particularly important in this context given the nature of the data we worked with, and the importance of short run dynamics.

2.47 The bounds testing approach involves two tests, with, in both cases, the null hypothesis being that the data are not cointegrated:

- an F-test is conducted on all the long run level variables; if this passes this suggests the relevant variables are long run drivers;
- a t-test is undertaken on the lagged level of the dependent variable (traffic); a failure to pass this test suggests information on the level of traffic is not needed to predict future levels, meaning that there would be no evidence of mean reversion.

2.48 All markets apart from FLRoW passed the bounds test at the 5% level using the upper bound figures. So, these results suggested that we can have a large degree of confidence in the existence of cointegration for these models.

### Autocorrelation of residuals

2.49 Autocorrelation of residuals is a common problem in time series econometrics; its existence violates the independent-residual assumption. The presence of autocorrelation was tested using the Breusch-Godfrey test.<sup>4</sup> We tested this using both one and two lags, and, where a second lagged term variable is included in the model, three lags. Where it was found to be a problem an additional lagged level dependent variable term was included in the model and tested.

2.50 The only preferred model to fail the autocorrelation test at the 5% level was the FLOECD market. We investigated adding further lagged terms, but this did not resolve the issue and so this model is caveated.

---

<sup>4</sup> We use the `bgtest` function in the `lmtest` package in R.

## Normality of residuals

2.51 Testing for normality of residuals was conducted using the Shapiro-Wilk test.<sup>5</sup> This was not found to be a problem in any of the markets.

## Heteroskedasticity

2.52 Testing for heteroskedasticity of residuals was conducted using the Breusch-Pagan test.<sup>6</sup> This was not found to be a problem in any of the markets.

## Ramsey RESET test

2.53 We undertook a Ramsey RESET test for mis-specification with respect to functional form. This involved regressing the dependent variable on various powers of predictions of the dependent variable (derived from the chosen model). For these tests, we tested using quadratic and cubic terms.<sup>7</sup>

2.54 The only preferred model to fail the test at the 5% level was the FLRoW market. We investigated adding quadratic terms to the model, but this did not resolve the issue. As such it does act as a caveat.

## Stability

2.55 For the model to be stable we required  $-2 < \theta_0 < 0$  in equation (1). This was the case in all markets. Stability was also confirmed through producing projections using a range of forecasts.

## Results of estimation and diagnosis

2.56 The estimated coefficients and associated t-statistics for all the sixteen estimated markets are shown in Table 3, with the diagnosis results reported in Table 4. We were not successful in estimating two markets: ULRoE and UBOECD.

2.57 The notation used for each of the variables is as set out in Table 2 below, using, by way of example the market for foreign residents travelling for leisure to and from Southern Europe (FLSE):

Description	Name
Number of foreign resident passengers travelling to and from Southern Europe for leisure	FLSE.tra
Foreign resident fares between UK and Southern Europe (and vice versa)	FLSE.FARE
UK consumption	CON
UK GDP	GDP
Foreign GDP for FLSE market	FLSE.FGDP

<sup>5</sup> Reported by the `dynardl.auto.correlated` function in the `dynamac` package in R.

<sup>6</sup> We use the `bptest` function in the `lmtest` package in R.

<sup>7</sup> This was implemented by using the `resettest` function, which is part of the `lmtest` package, setting the `type` parameter to 'fitted'.

Average of the (logged) indices relating to UK GDP and FLSE GDP	FLSE.AVEGDP
Imports from Southern Europe	FLSE.IMP
Exports to Southern Europe	FLSE.EXP
Average of the (logged) indices relating to FLSE.IMP and FLSE EXP	FLSE.TRADE
Exchange rates	FLSE.EXR
Dummy variable for 1991	d1991
Dummy variable for year being later than 2000	dPOST2000
Dummy interaction term. When the year is greater than 2000, takes the value of FLSE.FGDP in the current year minus FLSE.FGDP in 2000; is 0 for years 2000 and earlier	dPOST2000XFLSE.FGDP

**Table 2 Variable names**

2.58 The resulting long run income and price elasticities (after adjustments where applicable) for each market is set out in the Chapter 3. For the purpose of presenting the results, the income elasticity calculation involves summing up all the coefficients which are assumed to be driven by GDP – this includes all consumption and trade terms, but excludes the exchange rate, and dividing by the negative of the lagged level dependent variable term. Therefore this elasticity value implicitly assumes that all income drivers grow by the same rate, which we may not assume in our forecasting framework. Nevertheless, it provides a useful way of comparing elasticities across models and is consistent with the approach in the previous NAPDM.

2.59 The previous NAPDM model adjusted some of the econometrically estimated elasticities, and filled in gaps for the missing markets. We did the same this time, and this process is set out in the next section. We therefore defer comparison with the previous exercise’s elasticities until after these adjustments have been discussed.

2.60 Each market’s results are reported in more detail the Chapter 3.





Table 3 Parameter estimates and t-statistics

Market	Share of modelled traffic	Regression test statistics		Bounds test (p-values)		Diagnostics (p-values)					
		R2	F	Bounds test upper bound (F-test)	Bounds test upper bound (t-test)	Breusch - Godfrey (order 1)	Breusch - Godfrey (order 2)	Breusch - Godfrey (order 3)	Breusch - Pagan	Shapiro - Wilk	Reset : fitted
UBSE	2%	0.74	8.26	1%	1%	0.79	0.28		0.42	0.93	0.97
UBRoE	5%	0.77	22.70	1%	1%	0.17	0.14		0.24	0.87	0.17
UBRoW	1%	0.70	6.67	1%	1%	0.84	0.34		0.95	0.16	0.67
ULSE	25%	0.76	8.95	1%	1%	0.21	0.11		0.10	0.24	0.22
ULOEC D	4%	0.90	18.56	1%	1%	0.75	0.29		0.86	0.51	0.59
ULRoW	6%	0.90	17.26	1%	1%	0.44	0.26	0.11	0.85	0.61	0.58
FBSE	1%	0.76	16.2	1%	1%	0.38	0.44		0.43	0.85	0.94
FBRoE	4%	0.91	20.82	1%	1%	0.41	0.67		0.64	0.82	0.38
FBOEC D	1%	0.80	21.18	1%	5%	0.22	0.45		0.47	0.44	0.53
FBRoW	1%	0.89	31.97	5%	5%	0.97	0.82	0.08	0.43	0.42	0.71
FLSE	5%	0.85	11.1	1%	5%	0.08	0.14	0.26	0.47	0.46	0.39
FLRoE	11%	0.90	15.93	1%	1%	0.14	0.16		0.46	0.61	0.76
FLOEC D	3%	0.56	5.32	1%	1%	0.25	0.04		0.80	0.70	0.44
FLRoW	2%	0.96	48.76	5%	More than 10%	0.59	0.65		0.41	0.90	0.04
UBD	3%	0.83	10.99	1%	1%	0.08	0.03	0.03	0.09	0.91	0.74
ULD	3%	0.93	22.21	1%	1%	0.35	0.52		0.32	0.06	0.30

Note: The Bounds test is a cointegration test. A p-value lower than 5% rejects the null hypothesis which suggests cointegration exists – this is considered desirable for the model. The diagnostics tests for various econometric problems – failure to reject the null hypothesis i.e. a p-value above 0.05 is considered desirable.

Table 1: Results of diagnostic tests

## Missing markets and adjustments

### Missing markets

- 2.61 Despite numerous attempts, we have not been able to estimate credible models for the markets ULRoE and UBOECD.
- 2.62 For the ULRoE market the difficulty appeared to be a lack of cointegration – the coefficient on the lagged level of traffic was not found to be significant. We attempted different definitions of Europe – combining Southern Europe with Rest of Europe, and, separately, removing former Soviet Union countries and others – but with no success. Given the lack of cointegration, we also tried a first difference model but again were not successful.
- 2.63 For the UBOECD market, we tried to estimate a set of alternative models, and some diagnosis tests were passed. However, these models did not produce statistically significant income elasticity and coefficient estimates, and/or the estimation results were sensitive to the inclusion of year dummies that are important to explain the demand, which cast doubt on the model reliability.

### Override for missing markets

- 2.64 As discussed above, we were not successful in estimating two markets: ULRoE and UBOECD. Given the need to forecast the complete aviation market, we needed to make some assumptions about how to forecast them.
- 2.65 For ULRoE, we believed the most appropriate approach was to assume the market behaves in the same way as the one that seems most like it, ULSE. This is cautious, as the ULRoE market has grown by an average of 6% per annum over the forecast period, while the ULSE market has grown by 4% per annum.<sup>8</sup>
- 2.66 For UBOECD, there was evidence in model estimation to suggest that the market is no longer particularly sensitive to income growth; however, it did not seem plausible that the market would not grow at least in line with UK population, if fares were held constant. As such, it was assumed that this market effectively would grow at a rate equivalent to the growth in UK population. The OBR assume this to be an average of 0.14% per annum in the long term (OBR, 2020).
- 2.67 We translated this into an equivalent GDP elasticity of 0.1, for three reasons:
- it simplifies the implementation and data gathering required, as population is not forecasted to be a driver in any other model

---

<sup>8</sup> An alternative is instead to base the forecast parameters instead on the FLRoE market on the grounds that this is also a similar market, and it has seen similar rates of growth in the past (also 6% per annum). But this market composes a completely different group of passengers, and it may inflate the forecasts for the ULRoE market. A second alternative is to base it on an average of ULSE and FLRoE markets but this is more complicated, and there is no reason to believe it would be more accurate.

- it is consistent with what is currently assumed with respect to market maturity where in the low demand case, demand is assumed to eventually rise in line with population only and this is implemented through imposing an equivalent GDP elasticity<sup>9</sup>
- it is reasonable to assume there would be some demand changes in line with the economic cycle, notwithstanding the econometric results

2.68 We assumed a price elasticity of zero in this market, the same as estimated for FBOECD.

### Override for price elasticities

2.69 Overall, the evidence base relating to price elasticities was not as strong as we would have liked. Based on the estimation results shown in **Error! Reference source not found.**, there is a concern with the resulting price elasticities of demand, particularly those relating to short haul leisure. There are three sets of issues:

- we were sceptical of the fares data, especially those which relate to short haul leisure and for foreign residents.
- intuitively, the elasticities seem more inelastic than we expected a priori, given this is typically thought to be a price sensitive market.
- literature suggest the market is more elastic than this, although it is difficult to find studies that relate specifically to short haul Europe.<sup>10 xi</sup>

2.70 Therefore, we used an override for the ULSE price elasticity, using that estimated in the ULOECD market (that is, -1.1). We chose ULOECD as it is long haul and so has fewer data issues; further, the ULOECD market seems culturally more like ULSE than ULRoW. In addition, we applied the same model to ULRoE, this resulted in the ULRoE market also being given a price elasticity of -1.1.

2.71 For foreign residents travelling for leisure, we used the price elasticities associated with UK residents for all four foreign resident leisure markets.

### International-to-international (I-to-I) market

2.72 While I-to-I income elasticities were estimated from an econometric model in 2011 model, we did not attempt to derive the I-to-I market from econometric models in the current exercise, due to data quality issues.

2.73 Instead, its demand elasticities were estimated by using a weighted average of elasticities of eight foreign markets (i.e. four foreign business markets and four foreign leisure markets). All I-to-I travellers are by definition foreign passengers and are expected to have similar behaviour to those foreign resident markets. The weights of the eight relevant markets were the passenger proportions taken from CAA interview survey data in 2015. The I-to-I income elasticity is the weighted

---

<sup>9</sup> Market maturity is a process where we assume long run income elasticities decline over time. However, consideration of this process is not in the scope of this paper.

<sup>10</sup> For example, Smyth and Pearce (2008) suggests a price elasticity of -0.9 for short haul markets, substantially more elastic than what we have for the ULSE market, -0.3.

average with respect to foreign GDP elasticities of the eight foreign markets, while the price elasticity is with respect to the fare elasticities.

## Technical peer review

- 2.74 We sought expert academic advice to ensure the methods used were fit for purpose. Dr. Anthony Fowkes, at the Institute for Transport Studies, University of Leeds, evaluated the techniques being used to update the econometric models.. This includes the methodology used, and the proposed overrides to the econometrically estimated elasticities.
- 2.75 Dr Anthony Fowkes reviewed the international models and stated that the current state-of-the-art practice has been followed, and that no better elasticity estimates could have been obtained within the current form of modelling and data resource availability. The full academic review note describing the approach taken and limitations can be found in the Annex.
- 2.76 We did not submit the domestic models to peer review as they used the same methodology as the international models.

### 3. Results of econometric models

#### Long run air fare and income elasticities

3.1 Table 2 below reports the long-run elasticities derived from the current models and compares them to those obtained in the 2011 models.

	Previous 2011 model (using data to 2008)		Current model (using data to 2017)	
	YED	PED	YED	PED
UBD	0.9	-0.3	1.1	-0.2
ULD	1.4	-0.7	1.0	-1.0
UBSE	1.1	-0.3	0.6	-0.2
UBRoE	1.1	-0.3	1.1	0.0
UBOECD	0.9	0.0	0.1	0.0
UBRoW	0.9	0.0	0.4	-0.6
ULSE	1.2	-0.7	1.0	-1.1
ULRoE	1.2	-0.7	1.0	-1.1
ULOECD	1.2	-0.3	1.3	-1.1
ULRoW	1.4	-0.6	2.0	-0.9
FBSE	1.0	-0.2	1.1	-0.1
FBRoE	1.0	-0.2	0.7	-0.3
FBOECD	0.5	-0.2	0.9	0.0
FBRoW	0.7	0.0	1.2	-0.3
FLSE	1.1	-0.8	2.6	-1.1
FLRoE	1.1	-0.8	1.9	-1.1
FLOECD	0.5	-0.3	1.1	-1.1
FLRoW	0.5	-0.2	2.1	-0.9
I-to-I	0.4	-0.5	0.9	-0.9
Overall	1.1	-0.6	1.2	-0.9

	Previous 2011 model (using data to 2008)		Current model (using data to 2017)	
	YED	PED	YED	PED
All business	1.0	-0.2	0.9	-0.2
All leisure	1.2	-0.6	1.3	-1.1
Domestic	1.2	-0.5	1.1	-0.6
Southern Europe	1.2	-0.7	1.2	-1.0
Rest of Europe	1.1	-0.6	1.2	-0.9
OECD	0.9	-0.3	1.1	-0.9
Rest of World	1.1	-0.4	1.8	-0.9
All UK residents	1.2	-0.6	1.1	-0.9
All foreign residents	0.9	-0.5	1.6	-0.9

YED: income elasticity of demand

PED: price elasticity of demand

Cells in yellow reflect use of overrides

YEDs from the previous exercise have been reduced by 10% to reflect a different definition of GDP growth<sup>xii</sup>

In the markets where a structural break exists, it is the elasticities post the structural break that are shown

Where elasticities do not relate to a specific market, they are weighted

---

Table 2: Long run income and price elasticities

### Income elasticities

- 3.2 The overall income elasticity is almost unchanged. The UK resident income elasticity falls slightly from 1.2 to 1.1; this is not surprising given the cautious assumption made about the ULRoE market.
- 3.3 The biggest change relates to the income elasticities estimated for foreign passengers which has grown from 0.9 to 1.6. The increase in this elasticity is not surprising as this market has seen growth of almost 4% p.a. since 2008, despite weak GDP growth and low falls in fares.
- 3.4 But the size of the increase in the elasticity is surprising. To a large extent this seems to be driven by unintuitively low income elasticities estimated in 2008: the foreign leisure market had grown by about the same rate as the UK leisure market up to 2008, yet the elasticities were materially lower.<sup>11</sup> Additionally, the previous models excluded exchange rates: when we excluded it from the model estimated in the

---

<sup>11</sup> Although we have no concerns with the estimates associated with the previous model – we have been able to replicate the estimates ourselves using the same data.

current models, we find the income elasticity for the FLSE market declines from 2.6 to 1.8, thus explaining much of the discrepancy. We also find the previous traffic data used in the foreign leisure Rest of the World markets was volatile, perhaps not helped by the definition being based on terminal passengers rather than trips;<sup>12</sup> for the current models, we find the traffic data (which has been re-estimated over the entire period) more stable.

- 3.5 The business income elasticities are lower than those estimated before. This is largely driven by the fact that there has been low growth in this market since 2008 (only 0.3% growth p.a.).

### Price elasticities

- 3.6 The weighted average price elasticity is higher than the previous estimate. This is driven primarily by the use of more elasticity overrides for the current models. The fact that the elasticity estimates are determined largely by these judgements (which builds on the existing literature) is a caveat to this model.

### Updated econometric models and output

- 3.7 This section presents the detailed outputs of the econometric analysis for the preferred models for each of the fourteen international and two domestic passenger markets.<sup>13</sup>

### UK Business to Southern Europe (UBSE)

#### Econometric model output in R

- 3.8 The estimation results of the preferred econometric model are shown below:

---

<sup>12</sup> This would result in a passenger making a transfer at a UK being counted three times for a one-way trip. Therefore, if the number of direct connections increased over time, it would reduce the quantified increase in demand. This may have deflated the observed growth, decreasing estimated income elasticities.

<sup>13</sup> This excludes the two markets that we were not successful in estimation: ULRoE and UBOECD.



```
> summary(UBSE.ecm)

Time series regression with "ts" data:
Start = 1987, End = 2017

Call:
dynam(formula = d(UBSE.tra, 1) ~ 0 + d(UBSE.AVEGDP, 1) + d(UBSE.EXR,
1) + d(UBSE.FARE, 1) + L(UBSE.AVEGDP, 1) + L(UBSE.EXP, 1) +
L(UBSE.EXR, 1) + L(UBSE.FARE, 1) + L(UBSE.tra, 1), data = data2019m)

Residuals:
    Min       1Q   Median       3Q      Max
-0.115801 -0.030501  0.003556  0.024380  0.126229

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
d(UBSE.AVEGDP, 1)  1.65949    1.04517   1.588 0.125993
d(UBSE.EXR, 1)     0.07472    0.25520   0.293 0.772318
d(UBSE.FARE, 1)   -0.07138    0.19970  -0.357 0.724020
L(UBSE.AVEGDP, 1)  0.28400    0.13843   2.052 0.051767 .
L(UBSE.EXP, 1)     0.21419    0.10670   2.007 0.056594 .
L(UBSE.EXR, 1)     0.56643    0.22935   2.470 0.021373 *
L(UBSE.FARE, 1)   -0.17203    0.08448  -2.036 0.053388 .
L(UBSE.tra, 1)    -0.87506    0.19026  -4.599 0.000126 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

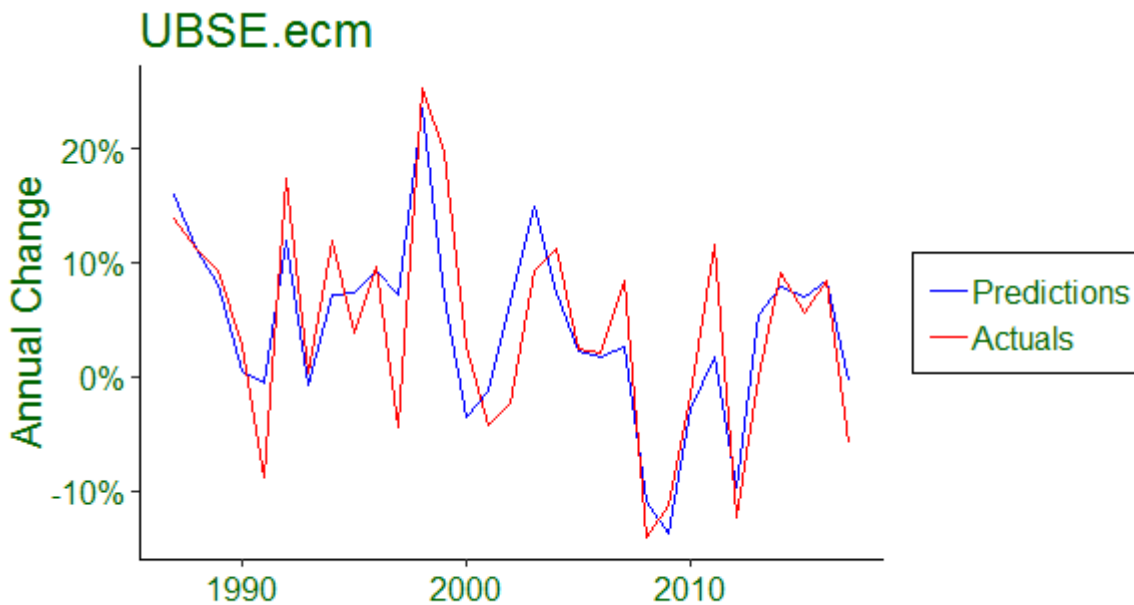
Residual standard error: 0.06032 on 23 degrees of freedom
Multiple R-squared:  0.7417,    Adjusted R-squared:  0.6519
F-statistic: 8.256 on 8 and 23 DF,  p-value: 3.14e-05
```

3.9 This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
Fare	-0.2	-0.3 to -0.1
Average of UK and FBSE GDP	0.3	0.1 to 0.6
Exchange rates	0.6	0.3 to 1.0
Exports	0.2	0.0 to 0.5

**Model fit**

3.10 The model predicted changes against actuals over time are plotted below:



## Conclusion and interpretation of model

3.11 The UBSE model appears to be both robust and provide credible results:

- the key drivers are statistically significant, of the “correct” sign and of plausible magnitude
- the resulting model uses data which are cointegrated
- none of the diagnostic tests reveal any difficulties.

3.12 Average (long run) GDP and exports combined have an estimated elasticity of 0.6 with a 95% confidence interval of 0.3 to 0.8.

3.13 All the long run elasticities seem plausible and are significant at or near the 5% level. The long run GDP elasticity is somewhat low, although given exports might also be expected to move in line with GDP, it does not seem unreasonable. The fares variable is inelastic which is to be expected from a business market.

## UK Business to Rest of Europe (UBRoE)

### Econometric model output in R

3.14 The estimation results of the preferred econometric model are shown below:

```
> summary(UBRoE.ecm)

Time series regression with "ts" data:
Start = 1987, End = 2017

Call:
dynlm(formula = d(UBRoE.tra, 1) ~ 0 + dPOST2006 + d(UBRoE.FGDP,
  1) + L(UBRoE.FGDP, 1) + L(UBRoE.tra, 1), data = data2019m)

Residuals:
    Min       1Q   Median       3Q      Max
-0.079107 -0.023425 -0.001299  0.016594  0.080345

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
dPOST2006      -0.04604    0.01678  -2.743  0.01067 *
d(UBRoE.FGDP, 1)  2.63889    0.43163   6.114 1.57e-06 ***
L(UBRoE.FGDP, 1)  0.17594    0.05108   3.444  0.00189 **
L(UBRoE.tra, 1) -0.16690    0.04708  -3.545  0.00146 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

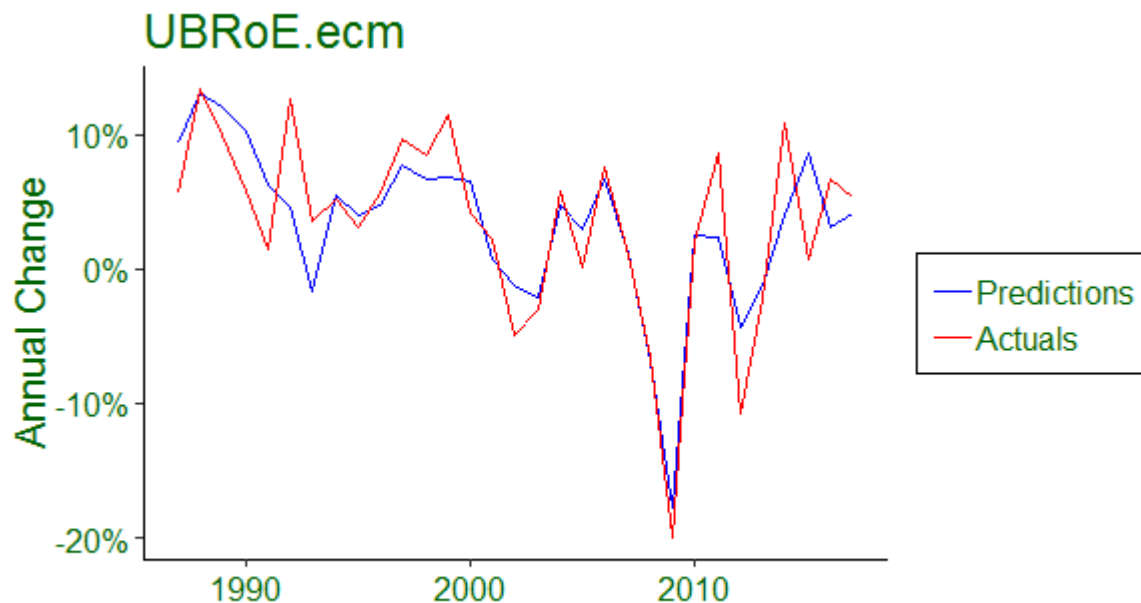
Residual standard error: 0.03966 on 27 degrees of freedom
Multiple R-squared:  0.7708,    Adjusted R-squared:  0.7368
F-statistic: 22.7 on 4 and 27 DF,  p-value: 2.632e-08
```

3.15 This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
UBRoE GDP	1.1	1.0 to 1.1

### Model fit

3.16 The model predicted changes against actuals over time are plotted below:



### Conclusion and interpretation of model

3.17 The UBRoE model appears to be both robust and provide credible results:

- the bounds test suggests there is cointegration
- the other diagnostic tests are also passed.

3.18 The model results in a very plausible GDP elasticity, and are significant at the 5% level. It is surprising the fares elasticity is not significant, although this is not implausible for a business market. The model suggests a permanent reduction in traffic (relative to the counterfactual) caused by the financial crisis.

### UK Business to Rest of the World (UBRoW)

#### Econometric model output in R

3.19 The estimation results of the preferred econometric model are shown below:

```
> summary(UBRow.ecm)
```

```
Time series regression with "ts" data:
Start = 1987, End = 2017
```

```
Call:
dynam(formula = d(UBRow.tra, 1) ~ 0 + +d(UBRow.AVEGDP, 1) + d(UBRow.EXR,
1) + L(UBRow.AVEGDP, 1) + L(UBRow.EXR, 1) + L(UBRow.FARE,
1) + d1990 + d1991 + L(UBRow.tra, 1), data = data2019m)
```

```
Residuals:
    Min       1Q   Median       3Q      Max
-0.098628 -0.044908 -0.007457  0.035234  0.159262
```

```
Coefficients:
              Estimate Std. Error t value Pr(>|t|)
d(UBRow.AVEGDP, 1)  0.94893    1.52508   0.622 0.539918
d(UBRow.EXR, 1)    0.68036    0.27825   2.445 0.022554 *
L(UBRow.AVEGDP, 1)  0.21319    0.09661   2.207 0.037590 *
L(UBRow.EXR, 1)    0.56206    0.15162   3.707 0.001161 **
L(UBRow.FARE, 1)  -0.30009    0.08375  -3.583 0.001574 **
d1990              -0.15324    0.08440  -1.816 0.082505 .
d1991              -0.24501    0.09721  -2.521 0.019107 *
L(UBRow.tra, 1)   -0.49597    0.11717  -4.233 0.000315 ***
```

```
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

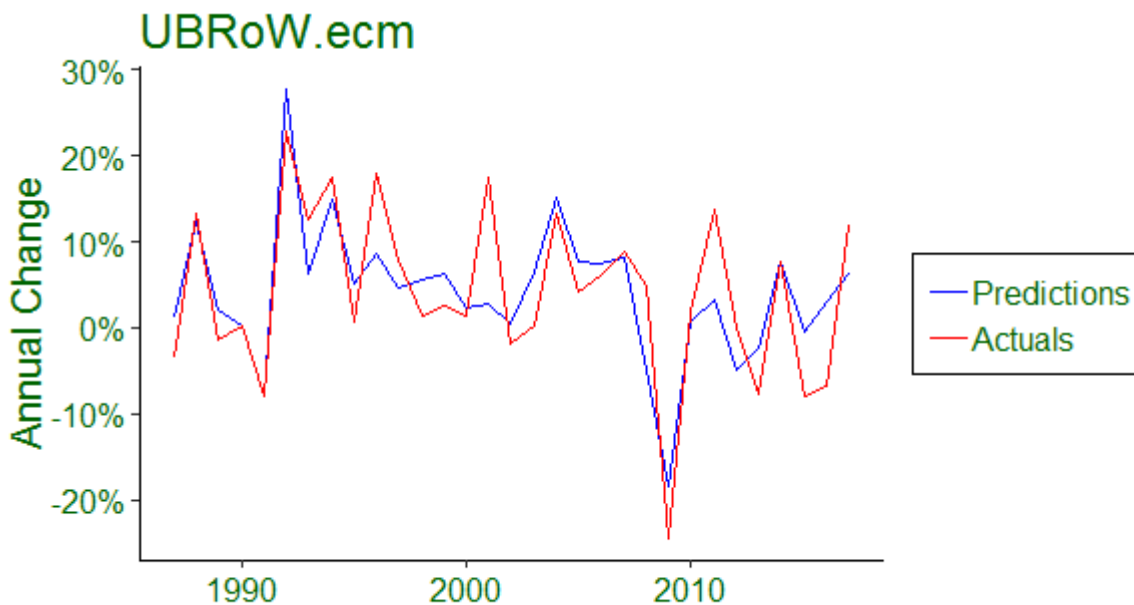
```
Residual standard error: 0.06714 on 23 degrees of freedom
Multiple R-squared:  0.6989,    Adjusted R-squared:  0.5941
F-statistic: 6.672 on 8 and 23 DF,  p-value: 0.0001567
```

3.20 This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
Fares	-0.6	-0.8 to -0.4
Average of UK and UBRoW GDP	0.4	0.1 to 0.7
Exchange rates	1.1	0.7 to 1.5

### Model fit

3.21 The model predicted changes against actuals over time are plotted below:



### Conclusion and interpretation of model

3.22 The UBRoW model provides credible results:

- the model passes the appropriate statistical tests, and there is strong evidence to suggest they are cointegrated
- further diagnostic tests are also passed.
- encouragingly, the model results in statistically significant plausible results for the long run variables of UK GDP, exchange rates and fares, although the exchange rate variable is higher than expected
- and the model also appears robust to minor reasonable changes to the specification, for example relating to the inclusion of dummy variables.

3.23 The fares and the GDP elasticities seem plausible. The GDP elasticity may seem lower than expected, but this is applied to a higher rate of GDP growth than for other markets.

## UK Leisure to Southern Europe (ULSE)

### Econometric model output in R

3.24 The estimation results of the preferred econometric model are shown below:

```
> summary(ULSE.ecm)

Time series regression with "ts" data:
start = 1987, End = 2017

Call:
dynlm(formula = d(ULSE.tra, 1) ~ 0 + d(GDP, 1) + d(ULSE.FARE,
1) + L(GDP, 1) + L(ULSE.EXR, 1) + L(ULSE.FARE, 1) + d1993 +
d1994 + L(ULSE.tra, 1), data = data2019m)

Residuals:
    Min       1Q   Median       3Q      Max
-0.09573 -0.01278  0.00000  0.02048  0.07633

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
d(GDP, 1)      2.59841    0.57608   4.510 0.000158 ***
d(ULSE.FARE, 1) -0.65079    0.18824  -3.457 0.002140 **
L(GDP, 1)       0.63106    0.15328   4.117 0.000421 ***
L(ULSE.EXR, 1)  0.22030    0.07860   2.803 0.010102 *
L(ULSE.FARE, 1) -0.22113    0.04968  -4.451 0.000183 ***
d1993          0.09681    0.05005   1.934 0.065508 .
d1994          0.15367    0.05106   3.010 0.006246 **
L(ULSE.tra, 1) -0.65250    0.14609  -4.467 0.000176 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

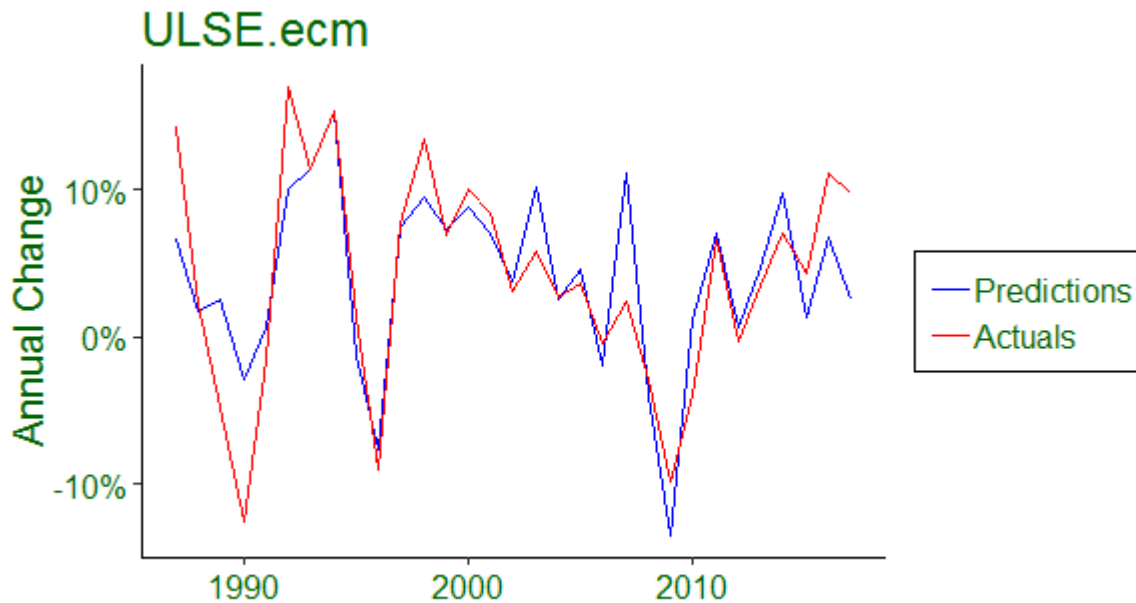
Residual standard error: 0.04725 on 23 degrees of freedom
Multiple R-squared:  0.7568,    Adjusted R-squared:  0.6722
F-statistic: 8.947 on 8 and 23 DF,  p-value: 1.659e-05
```

3.25 This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
Fare	-0.3	-0.4 to -0.3
UK GDP	1.0	0.8 to 1.2
Exchange rate	0.3	0.2 to 0.5

### Model fit

3.26 The model predicted changes against actuals over time are plotted below:



### Conclusion and interpretation of model

3.27 The ULSE model appears to be both robust and provide credible results:

- the model passes the appropriate statistical tests and there is strong evidence to suggest they are cointegrated
- further diagnostic tests are also passed
- encouragingly, the model results in statistically significant results for the long run variables of UK GDP, exchange rates and fares
- the values of the GDP and exchange rate elasticities are plausible
- the UK GDP and exchange rate elasticities look entirely plausible and are significant at the 5% level
- the model also appears robust to minor reasonable changes to the specification, for example relating to the inclusion of dummy variables.

3.28 The fares variable appears more inelastic than might be expected – this may be because the fares data does not capture some increases in non-fare charges that have occurred over the past 20 years, which are particularly relevant for this sector. This could cause bias in the fares data. The fares data show a large reduction in fares over time, but this does not take into account unbundling – that is, some of this fare reduction has been offset by new charges for luggage and food / drink etc. If the decline in fares has been overstated, we would expect this to lead to an underestimate of the elasticity.

### UK Leisure to OECD (ULOECD)

#### Econometric model output in R

3.29 The estimation results of the preferred econometric model are shown below:

## Econometric Models to Estimate Demand Elasticities for the National Air Passenger Demand Model

```
> summary(ULOECD.ecm)
```

```
Time series regression with "ts" data:  
Start = 1987, End = 2017
```

```
call:  
dynlm(formula = d(ULOECD.tra) ~ 0 + dPOST2000 + d(GDP, 1) + d(dPOST2000XGDP,  
1) + d(ULOECD.FARE, 1) + L(GDP, 1) + L(dPOST2000XGDP, 1) +  
L(ULOECD.FARE, 1) + d1994 + d2010 + L(ULOECD.tra, 1), data = data2019m)
```

```
Residuals:  
      Min       1Q   Median       3Q      Max  
-0.090595 -0.025529  0.002444  0.025435  0.054178
```

```
Coefficients:  
              Estimate Std. Error t value Pr(>|t|)  
dPOST2000      -0.17831   0.03962  -4.501 0.000196 ***  
d(GDP, 1)       1.58365   0.68997   2.295 0.032121 *  
d(dPOST2000XGDP, 1) 0.75905   0.90722   0.837 0.412194 .  
d(ULOECD.FARE, 1)  -0.32920   0.18105  -1.818 0.083310 .  
L(GDP, 1)       1.47055   0.34305   4.287 0.000327 ***  
L(dPOST2000XGDP, 1) -0.60829   0.26522  -2.294 0.032234 *  
L(ULOECD.FARE, 1)  -0.75810   0.19620  -3.864 0.000899 ***  
d1994          -0.12057   0.04496  -2.682 0.013965 *  
d2010          -0.11141   0.04585  -2.430 0.024152 *  
L(ULOECD.tra, 1)  -0.68192   0.15072  -4.524 0.000186 ***  
---  
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

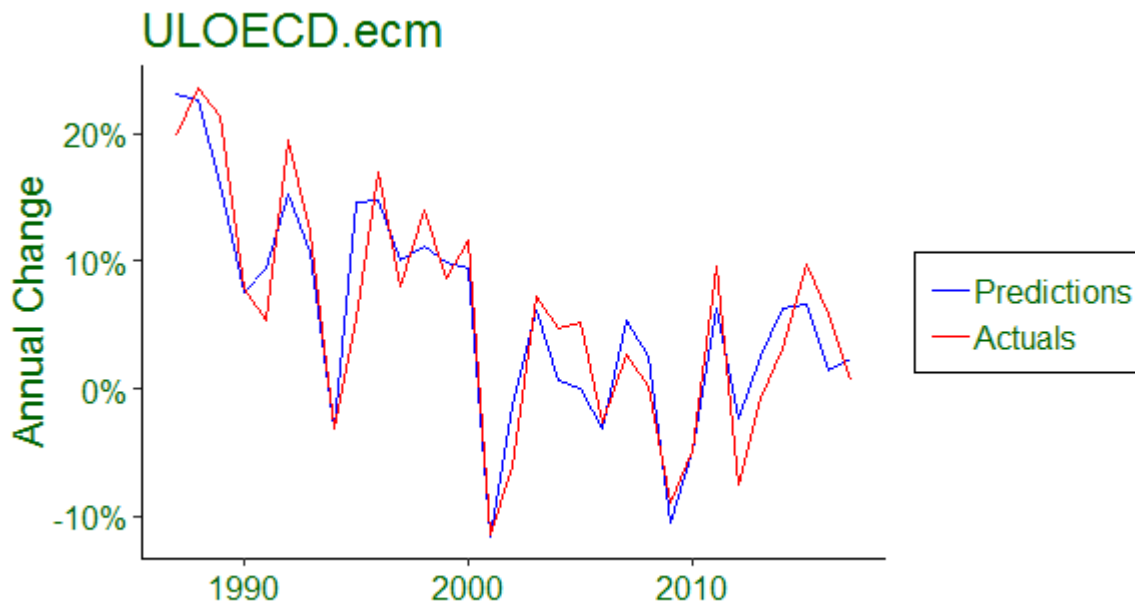
```
Residual standard error: 0.04108 on 21 degrees of freedom  
Multiple R-squared:  0.8984, Adjusted R-squared:  0.85  
F-statistic: 18.56 on 10 and 21 DF, p-value: 2.979e-08
```

3.30 This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
Fare	-1.1	-1.3 to -1.0
UK GDP (pre-2001)	2.2	2.0 to 2.3
UK GDP (post-2000)	1.3	0.8 to 1.7

### Model fit

3.31 The model predicted changes against actuals over time are plotted below:



## Conclusion and interpretation of model

3.32 The ULOECD model appears to be both robust and provide credible results. The key long run variables of fares and GDP are statistically significant, although the exchange rate term is not. It passes the relevant diagnostic tests and there is evidence that the data are cointegrated.

3.33 The long run elasticities seem plausible and are significant at or near the 5% level.

## UK Leisure to Rest of World (ULRoW)

### Econometric model output in R

3.34 The estimation results of the preferred econometric model are shown below:

```
> summary(ULRow.ecm)

Time series regression with "ts" data:
Start = 1988, End = 2017

Call:
dynam(formula = d(ULRow.tra, 1) ~ 0 + d(CON, 1) + d(ULRow.FARE,
  1) + L(d(ULRow.FARE, 1), 1) + L(CON, 1) + L(ULRow.FARE, 1) +
  d1990 + d1991 + d2002 + L(ULRow.tra, 1) + L(d(ULRow.tra,
  1), 1), data = data2019m)

Residuals:
    Min       1Q   Median       3Q      Max
-0.08075 -0.02013  0.00000  0.02157  0.05845

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
d(CON, 1)          0.38672   0.48302   0.801 0.432747
d(ULRow.FARE, 1)  -0.26035   0.14236  -1.829 0.082384 .
L(d(ULRow.FARE, 1), 1) 0.37649   0.14932   2.521 0.020284 *
L(CON, 1)          1.11296   0.22967   4.846 9.80e-05 ***
L(ULRow.FARE, 1)   -0.53490   0.12818  -4.173 0.000469 ***
d1990              -0.10150   0.05011  -2.026 0.056359 .
d1991              -0.16011   0.05302  -3.020 0.006770 **
d2002              -0.16560   0.04216  -3.928 0.000833 ***
L(ULRow.tra, 1)   -0.56339   0.10821  -5.207 4.28e-05 ***
L(d(ULRow.tra, 1), 1)  0.34466   0.12346   2.792 0.011266 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.03939 on 20 degrees of freedom
Multiple R-squared:  0.8961,    Adjusted R-squared:  0.8442
F-statistic: 17.26 on 10 and 20 DF,  p-value: 9.829e-08
```

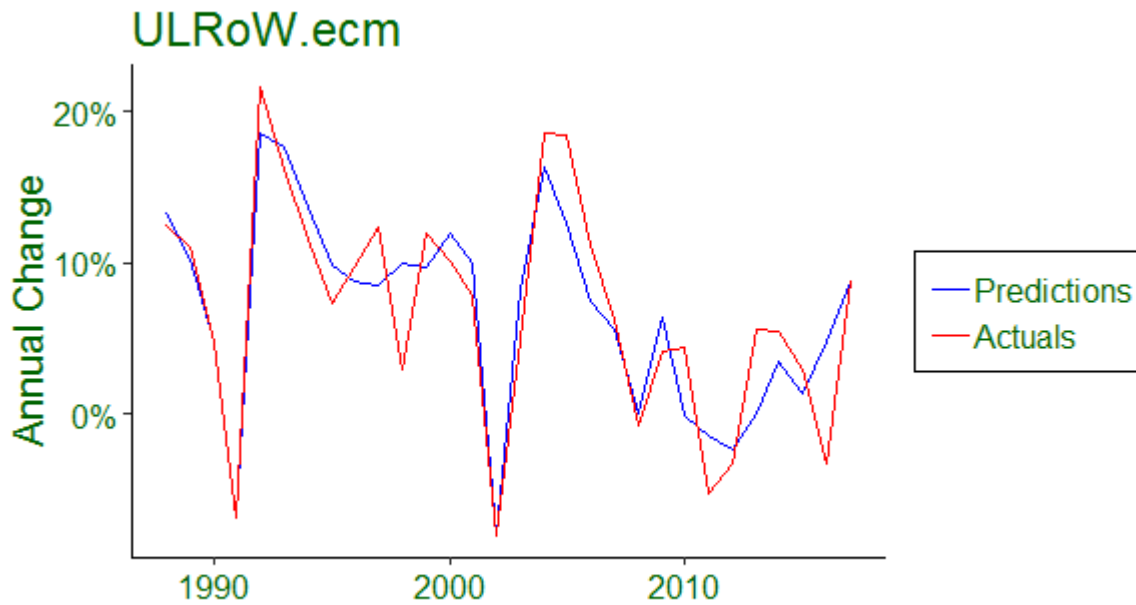
3.35 This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
Fare	-0.9	-1.1 to -0.8
UK consumption	2.0	1.9 to 2.1

### Model fit

3.36 The model predicted changes against actuals over time are plotted below:





### Conclusion and interpretation of model

3.37 The ULRoW model appears to be both robust and provide credible results:

- the model passes the appropriate statistical tests
- there is good evidence to suggest the data are cointegrated
- the consumption and fares variables are statistically significant
- the model also appears broadly robust to minor reasonable changes to the specification, for example relating to the inclusion of dummy variables.

3.38 Both elasticities seem plausible. The consumption elasticity is high, but that is not surprising given it relates to a relatively immature market. Both elasticities are statistically significant at the 5% level. Using UK GDP instead of consumption results in a statistically insignificant variable, and so UK consumption is preferred. However, it is reassuring to note that although UK GDP is used rather than consumption, both result in almost identical elasticities.

### Foreign Business to Southern Europe (FBSE)

#### Econometric model output in R

The estimation results of the preferred econometric model are shown below:

```
> summary(FBSE.ecm)

Time series regression with "ts" data:
Start = 1987, End = 2017

Call:
dynam(formula = d(FBSE.tra, 1) ~ 0 + d(FBSE.IMP, 1) + L(FBSE.IMP,
  1) + L(FBSE.FARE, 1) + d2002 + L(FBSE.tra, 1), data = data2019m)

Residuals:
    Min       1Q   Median       3Q      Max
-0.115119 -0.026593 -0.000308  0.027152  0.098119

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
d(FBSE.IMP, 1)  0.73073    0.14656   4.986 3.49e-05 ***
L(FBSE.IMP, 1)  0.51287    0.13331   3.847 0.000695 ***
L(FBSE.FARE, 1) -0.03316    0.01818  -1.824 0.079663 .
d2002          -0.17440    0.05088  -3.428 0.002038 **
L(FBSE.tra, 1) -0.48044    0.12481  -3.849 0.000692 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

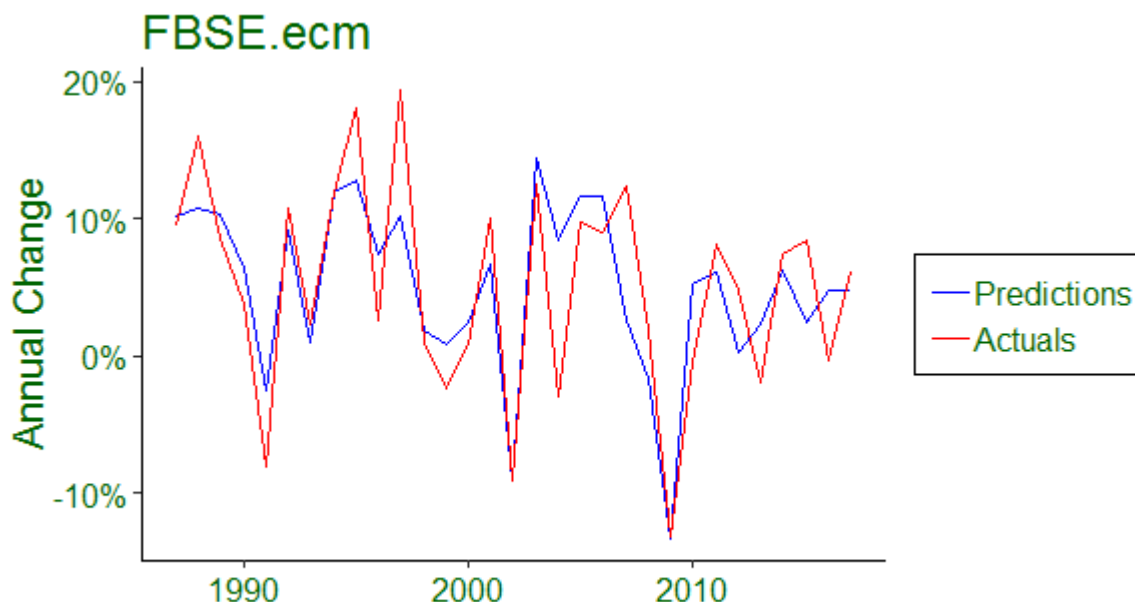
Residual standard error: 0.04919 on 26 degrees of freedom
Multiple R-squared:  0.757,    Adjusted R-squared:  0.7103
F-statistic: 16.2 on 5 and 26 DF, p-value: 2.835e-07
```

This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
Fares	-0.1	-0.1 to 0.0
Imports	1.1	1.0 to 1.1

### Model fit

3.39 The model predicted changes against actuals over time are plotted below:



### Conclusion and interpretation of model

3.40 The FBSE model appears to provide credible results:

- the model passes the appropriate statistical tests and there is strong evidence to suggest the data are cointegrated
- further diagnostic tests are also passed
- encouragingly, the model results in statistically significant and plausible results for the long run variables of imports (that is, exports from Southern Europe to the UK) and fares
- no measure of GDP is significant in this model but given the correlation between imports and GDP this is not concerning.

3.41 Both elasticities are plausible – it is not surprising that fares are found to be inelastic in a business market. Although the fares variable is statistically significant at only the 10% level, the fares elasticity is significant at the 5% level.

## Foreign Business to Rest of Europe (FBRoE)

### Econometric model output in R

3.42 The estimation results of the preferred econometric model are shown below:

```
> summary(FBRoE.ecm)

Time series regression with "ts" data:
Start = 1987, End = 2017

Call:
dynlm(formula = d(FBRoE.tra, 1) ~ 0 + dPOST2000 + d(FBRoE.AVEGDP,
  1) + d(FBRoE.TRADE, 1) + d(dPOST2000XFBRoE.TRADE, 1) + L(FBRoE.AVEGDP,
  1) + L(FBRoE.TRADE, 1) + L(dPOST2000XFBRoE.TRADE, 1) + L(FBRoE.FARE,
  1) + d1993 + L(FBRoE.tra, 1), data = data2019m)

Residuals:
    Min       1Q   Median       3Q      Max
-0.058709 -0.016943 -0.001189  0.019951  0.043660

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
dPOST2000      -0.11411    0.02858  -3.992 0.000662 ***
d(FBRoE.AVEGDP, 1)  2.09574    0.36103   5.805 9.22e-06 ***
d(FBRoE.TRADE, 1)   0.51585    0.17840   2.892 0.008731 **
d(dPOST2000XFBRoE.TRADE, 1) -0.34656    0.21769  -1.592 0.126328
L(FBRoE.AVEGDP, 1)  0.36987    0.08899   4.156 0.000447 ***
L(FBRoE.TRADE, 1)   0.37503    0.09140   4.103 0.000508 ***
L(dPOST2000XFBRoE.TRADE, 1) -0.35964    0.07911  -4.546 0.000176 ***
L(FBRoE.FARE, 1)   -0.18139    0.04697  -3.862 0.000904 ***
d1993           -0.07602    0.03218  -2.362 0.027909 *
L(FBRoE.tra, 1)   -0.56730    0.09847  -5.761 1.02e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

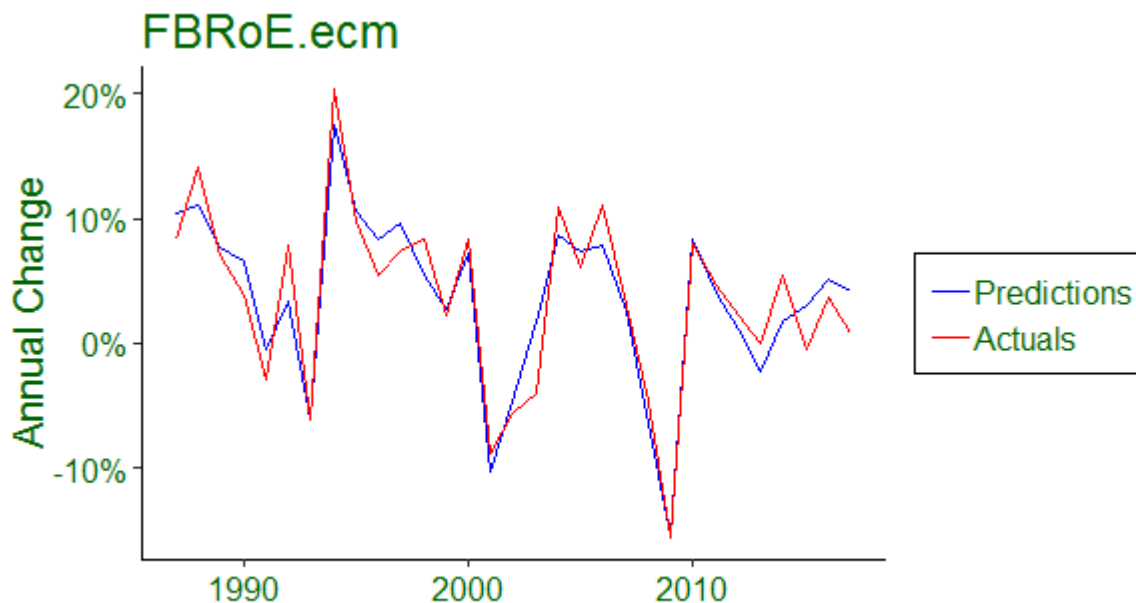
Residual standard error: 0.0295 on 21 degrees of freedom
Multiple R-squared:  0.9084,    Adjusted R-squared:  0.8648
F-statistic: 20.82 on 10 and 21 DF,  p-value: 1.042e-08
```

3.43 This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
Fare	-0.3	-0.5 to -0.1
Average of UK & FBRoE GDP	0.7	0.3 to 1.0
Trade (pre-2001)	0.7	0.5 to 0.8
Trade (post-2000)	0.0	-0.2 to 0.2

## Model fit

3.44 The model predicted changes against actuals over time are plotted below:



## Conclusion and interpretation of model

3.45 The FBRoE model provides credible results, given the structural break after the year 2000:

- the model passes the appropriate statistical tests
- there is evidence to suggest they are cointegrated.
- encouragingly, the model results in statistically significant and plausible results for the long run variables of GDP and fares, and trade up to the year 2000.

3.46 There appears to be a structural break after the year 2000 – there is a permanent drop in demand in the following year, and the trade elasticity appears to drop to zero. The latter effect could potentially be caused by the significant improvement in telecommunications which occurred from the early 2000s, although it could also be picking up a general decline in the responsiveness of traffic to economic activity following 9/11.

3.47 Average (long run) GDP and (post-2000) trade combined have an estimated elasticity of 0.7 with a 95% confidence interval of 0.5 to 0.9. The resulting elasticity of 0.7 of traffic to the average of UK and rest of Europe GDP seems reasonable, as does a price elasticity of -0.3 for a business market.

## Foreign Business to OECD (FBOECD)

### Econometric model output in R

3.48 The estimation results of the preferred econometric model are shown below:

```
> summary(FBOECD.ecm)

Time series regression with "ts" data:
Start = 1987, End = 2017

Call:
dynlm(formula = d(FBOECD.tra, 1) ~ 0 + +d(FBOECD.FGDP, 1) + L(FBOECD.FGDP,
1) + d1993 + d1994 + L(FBOECD.tra, 1), data = data2019m)

Residuals:
    Min       1Q   Median       3Q      Max
-0.087682 -0.049974 -0.002454  0.037010  0.136425

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
d(FBOECD.FGDP, 1)  6.12153    0.78499   7.798 2.85e-08 ***
L(FBOECD.FGDP, 1)  0.13184    0.05134   2.568 0.016320 *
d1993              0.27201    0.06078   4.475 0.000134 ***
d1994             -0.25675    0.06372  -4.029 0.000433 ***
L(FBOECD.tra, 1)  -0.15333    0.05037  -3.044 0.005290 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

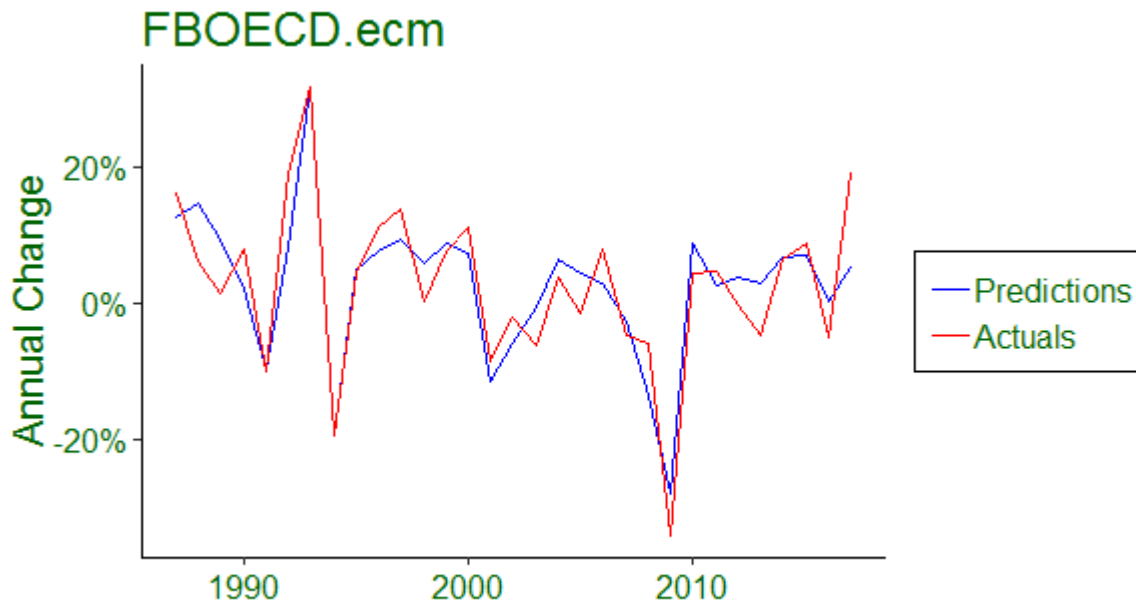
Residual standard error: 0.05965 on 26 degrees of freedom
Multiple R-squared:  0.8029,    Adjusted R-squared:  0.765
F-statistic: 21.18 on 5 and 26 DF,  p-value: 2.024e-08
```

3.49 This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
FBOECD GDP	0.9	0.7 to 1.0

### Model fit

3.50 The model predicted changes against actuals over time are plotted below:



### Conclusion and interpretation of model

3.51 The FBOECD model appears to be both robust and provide credible results:

- the model passes the appropriate statistical tests
- the data appear to be  $I(1)$
- there is some (albeit tentative) evidence to suggest data are cointegrated
- further diagnostic tests are also passed.
- the model results in statistically significant results for the long run variable of Foreign GDP with a magnitude which seems plausible
- the model also appears robust to minor reasonable changes to the specification, for example relating to the inclusion of dummy variables.

3.52 As might be expected OECD GDP is statistically significant with a plausible elasticity of 1.

### Foreign Business to Rest of the World (FBRoW)

#### Econometric model output in R

3.53 The estimation results of the preferred econometric model are shown below:

```
> summary(FBRow.ecm)
```

```
Time series regression with "ts" data:
start = 1988, End = 2017
```

```
Call:
dynlm(formula = d(FBRow.tra, 1) ~ 0 + +d(CON, 1) + L(CON, 1) +
L(FBRow.FARE, 1) + d1993 + L(FBRow.tra, 1) + L(d(FBRow.tra,
1), 1), data = data2019m)
```

```
Residuals:
    Min       1Q   Median       3Q      Max
-0.095704 -0.024123  0.002158  0.023795  0.109702
```

```
Coefficients:
                Estimate Std. Error t value Pr(>|t|)
d(CON, 1)         2.00530    0.59108   3.393  0.00240 **
L(CON, 1)         0.40286    0.10989   3.666  0.00122 **
L(FBRow.FARE, 1)  -0.10277    0.04040  -2.544  0.01782 *
d1993            0.67027    0.06375  10.514 1.83e-10 ***
L(FBRow.tra, 1)  -0.32301    0.10287  -3.140  0.00444 **
L(d(FBRow.tra, 1), 1) -0.30131    0.08937  -3.371  0.00253 **
```

```
---
signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

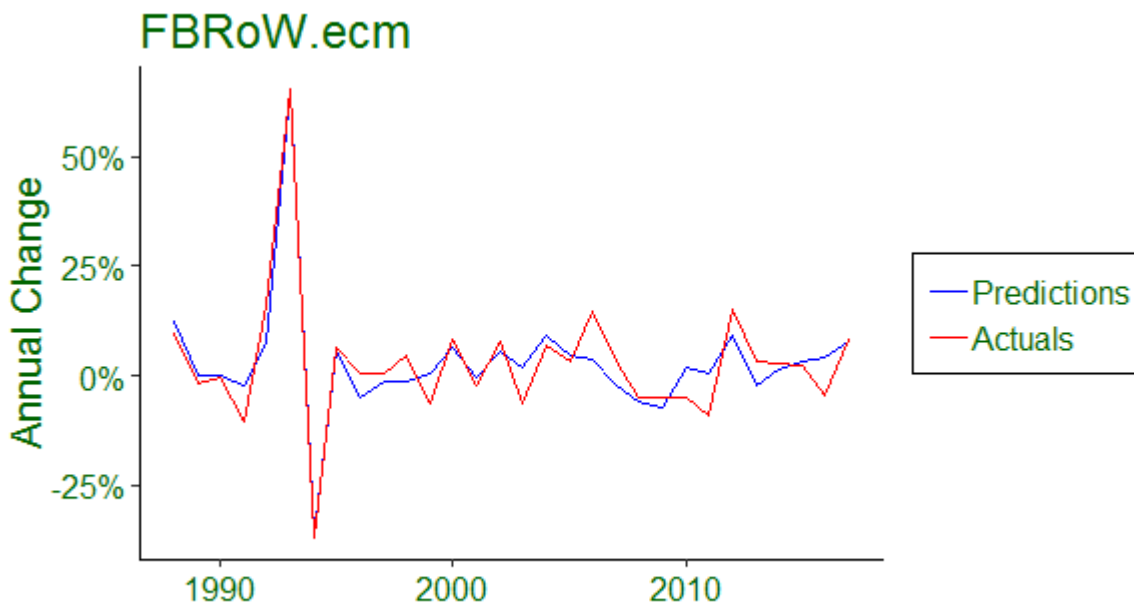
```
Residual standard error: 0.05757 on 24 degrees of freedom
Multiple R-squared:  0.8888,    Adjusted R-squared:  0.861
F-statistic: 31.97 on 6 and 24 DF,  p-value: 2.622e-10
```

3.54 This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
Fares	-0.3	-0.6 to 0.0
UK consumption	1.2	1.0 to 1.5

### Model fit

3.55 The model predicted changes against actuals over time are plotted below:



## Conclusion and interpretation of model

3.56 The FBRoW model appears to provide credible results:

- the model passes the appropriate statistical test
- the data appear to be I(1)
- the bounds test provides strong evidence to suggest data are cointegrated
- further diagnostic tests are also passed.
- encouragingly, the model results in statistically significant and plausible results for the long run variables of UK consumption and fares.

3.57 Both elasticities are very plausible – we would expect fares to be relatively inelastic given this is a business market.

## Foreign Leisure to Southern Europe (FLSE)

### Econometric model output in R

3.58 The estimation results of the preferred econometric model are shown below:

```
Time series regression with "ts" data:
Start = 1988, End = 2017

Call:
dynam(formula = d(FLSE.tra, 1) ~ 0 + d(FLSE.AVEGDP, 1) + d(FLSE.EXR,
1) + d(FLSE.FARE, 1) + L(FLSE.AVEGDP, 1) + L(FLSE.EXR, 1) +
L(FLSE.FARE, 1) + d1994 + d2002 + L(FLSE.tra, 1) + L(d(FLSE.tra,
1), 1), data = data2019m)

Residuals:
    Min       1Q   Median       3Q      Max
-0.092244 -0.026261  0.006758  0.027171  0.064985

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
d(FLSE.AVEGDP, 1)  2.29234    0.70654   3.244  0.00406 **
d(FLSE.EXR, 1)    -0.36016    0.15313  -2.352  0.02903 *
d(FLSE.FARE, 1)   -0.05783    0.16659  -0.347  0.73212
L(FLSE.AVEGDP, 1)  0.68560    0.20537   3.338  0.00327 **
L(FLSE.EXR, 1)    -0.23641    0.11287  -2.094  0.04916 *
L(FLSE.FARE, 1)   -0.17093    0.04622  -3.698  0.00142 **
d1994              0.13051    0.05088   2.565  0.01846 *
d2002              -0.18403    0.04996  -3.684  0.00147 **
L(FLSE.tra, 1)    -0.26689    0.07071  -3.775  0.00119 **
L(d(FLSE.tra, 1), 1) -0.25763    0.11883  -2.168  0.04239 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.0454 on 20 degrees of freedom
Multiple R-squared:  0.8473, Adjusted R-squared:  0.7709
F-statistic: 11.1 on 10 and 20 DF, p-value: 3.8e-06
```

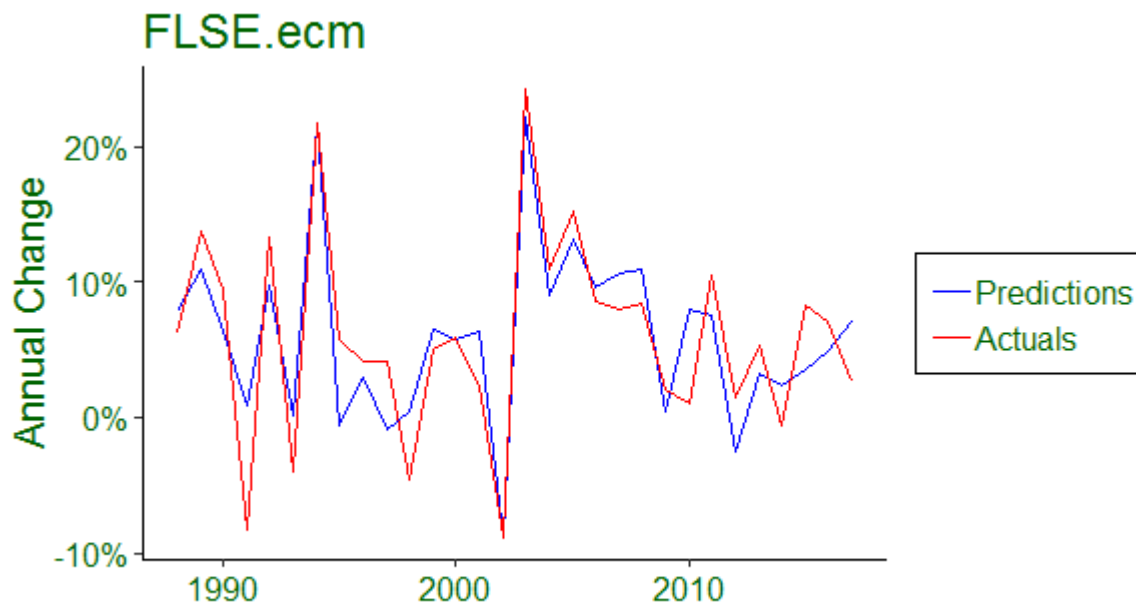
3.59 This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
Fare	-0.6	-0.8 to -0.5
Average of UK and FLSE GDP	2.6	2.0 to 3.2
Exchange rate	-0.9	-1.5 to -0.3



## Model fit

3.60 The model predicted changes against actuals over time are plotted below:



## Conclusion and interpretation of model

3.61 The FLSE model appears to provide credible results:

- there is some evidence to suggest the data are cointegrated
- further diagnostic tests are passed.
- encouragingly, the model results in statistically significant plausible results for the long run variables of UK GDP, exchange rates and fares, although there are good reasons the fares elasticity may be too inelastic.

3.62 The yearly dummies play a material role in influencing the results, but there are good a priori reasons for their inclusion so this is not a significant cause for concern.

3.63 There is a risk of autocorrelation in the residuals although the p-value is above 0.05 so the evidence of autocorrelation is not overwhelming.

3.64 The GDP elasticity looks high, but arguably not implausibly so given the strong growth in this market over the past thirty years. The exchange rate elasticity is of the intuitive sign and seems of a plausible magnitude.

## Foreign Leisure to Rest of Europe (FLRoE)

### Econometric model output in R

3.65 The estimation results of the preferred econometric model are shown below:

## Econometric Models to Estimate Demand Elasticities for the National Air Passenger Demand Model

```
> summary(FLRoE.ecm)
```

```
Time series regression with "ts" data:  
Start = 1987, End = 2017
```

```
Call:  
dynlm(formula = d(FLRoE.tra, 1) ~ 0 + d(FLRoE.AVEGDP, 1) + d(FLRoE.EXR,  
1) + d(FLRoE.FARE, 1) + L(FLRoE.AVEGDP, 1) + L(FLRoE.EXR,  
1) + L(FLRoE.FARE, 1) + d1994 + d1993 + d2001 + d2002 + L(FLRoE.tra,  
1), data = data2019m)
```

```
Residuals:  
Min      1Q  Median      3Q      Max  
-0.05481 -0.02223  0.00000  0.02469  0.05464
```

```
Coefficients:  
              Estimate Std. Error t value Pr(>|t|)  
d(FLRoE.AVEGDP, 1)  1.59821    0.58289   2.742 0.012570 *  
d(FLRoE.EXR, 1)     -0.34406    0.13977  -2.462 0.023043 *  
d(FLRoE.FARE, 1)    -0.04131    0.18210  -0.227 0.822844  
L(FLRoE.AVEGDP, 1)  0.98383    0.26175   3.759 0.001236 **  
L(FLRoE.EXR, 1)     -0.32964    0.13675  -2.411 0.025674 *  
L(FLRoE.FARE, 1)    -0.11434    0.04245  -2.693 0.013977 *  
d1994                0.11671    0.04125   2.830 0.010356 *  
d1993               -0.11566    0.03993  -2.896 0.008927 **  
d2001                -0.09180    0.04050  -2.267 0.034642 *  
d2002               -0.11473    0.03972  -2.889 0.009083 **  
L(FLRoE.tra, 1)     -0.52287    0.12804  -4.084 0.000578 ***
```

```
---  
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

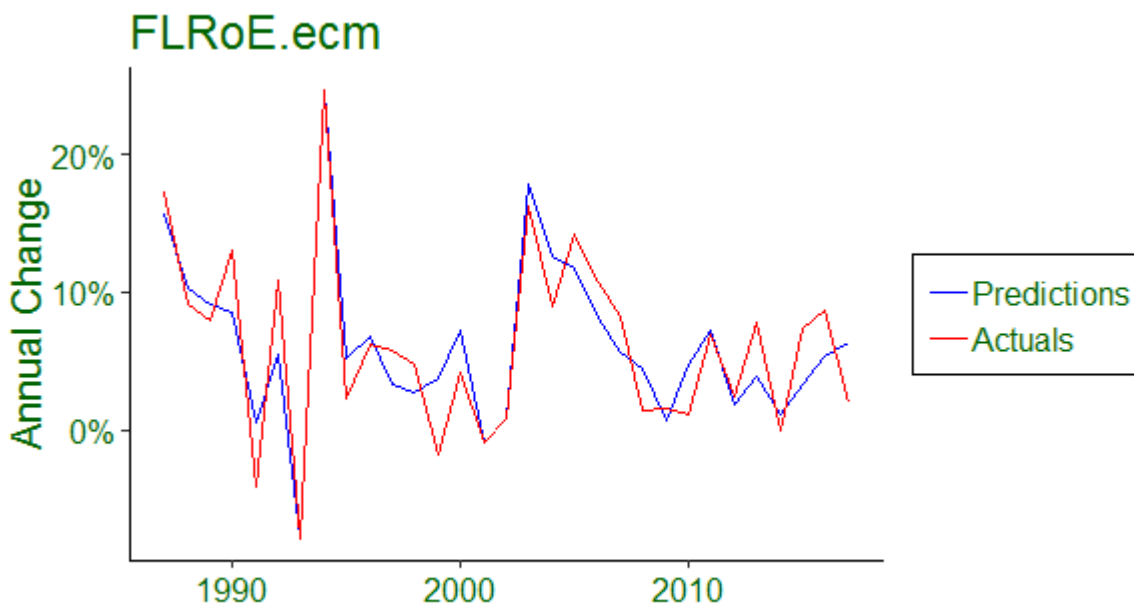
```
Residual standard error: 0.03597 on 20 degrees of freedom  
Multiple R-squared:  0.8976,    Adjusted R-squared:  0.8413  
F-statistic: 15.93 on 11 and 20 DF,  p-value: 1.443e-07
```

3.66 This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
Fare	-0.2	-0.4 to -0.1
Average of UK and Rest of Europe GDP	1.9	1.7 to 2.0
Exchange rate	-0.6	-0.9 to -0.3

### Model fit

3.67 The model predicted changes against actuals over time are plotted below:



## Conclusion and interpretation of model

3.68 The FLRoE model appears to be both robust and provide credible results:

- the model provides largely intuitive results.
- it passes the cointegration test and the relevant diagnostic tests.

3.69 There is a concern about the fares elasticity although there are well understood reasons for this being biased towards zero.

3.70 The relevant variables are statistically significant and of intuitive signs – the exchange rate variable is negative as a strong pound makes it more expensive for overseas residents to spend money in the UK. The GDP elasticity is high, but given traffic growth has had a CAGR<sup>14</sup> of about 6% over the relevant period (and about 4% in the past 10 years), this seems plausible. The fares variable seems to have a very low elasticity, most likely for data reasons.

## Foreign Leisure to OECD (FLOECD)

### Econometric model output in R

3.71 The estimation results of the preferred econometric model are shown below:

```
> summary(FLOECD.ecm)
```

```
Time series regression with "ts" data:
start = 1987, End = 2017
```

```
Call:
dynlm(formula = d(FLOECD.tra, 1) ~ 0 + dPOST2000 + d(FLOECD.FGDP,
  1) + d(FLOECD.FARE, 1) + L(FLOECD.FGDP, 1) + L(FLOECD.FARE,
  1) + L(FLOECD.tra, 1), data = data2019m)
```

```
Residuals:
    Min       1Q   Median       3Q      Max
-0.111738 -0.042678 -0.001556  0.039891  0.113339
```

```
Coefficients:
                Estimate Std. Error t value Pr(>|t|)
dPOST2000        -0.16156   0.06178  -2.615 0.014905 *
d(FLOECD.FGDP, 1)  2.87025   1.14084   2.516 0.018664 *
d(FLOECD.FARE, 1) -0.30261   0.23106  -1.310 0.202221
L(FLOECD.FGDP, 1)  0.91162   0.21887   4.165 0.000324 ***
L(FLOECD.FARE, 1) -0.09902   0.06782  -1.460 0.156734
L(FLOECD.tra, 1) -0.81079   0.18096  -4.480 0.000143 ***
```

```
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Residual standard error: 0.06683 on 25 degrees of freedom
Multiple R-squared:  0.5607,    Adjusted R-squared:  0.4552
F-statistic: 5.317 on 6 and 25 DF,  p-value: 0.001183
```

3.72 This results in the following estimated long run elasticities:

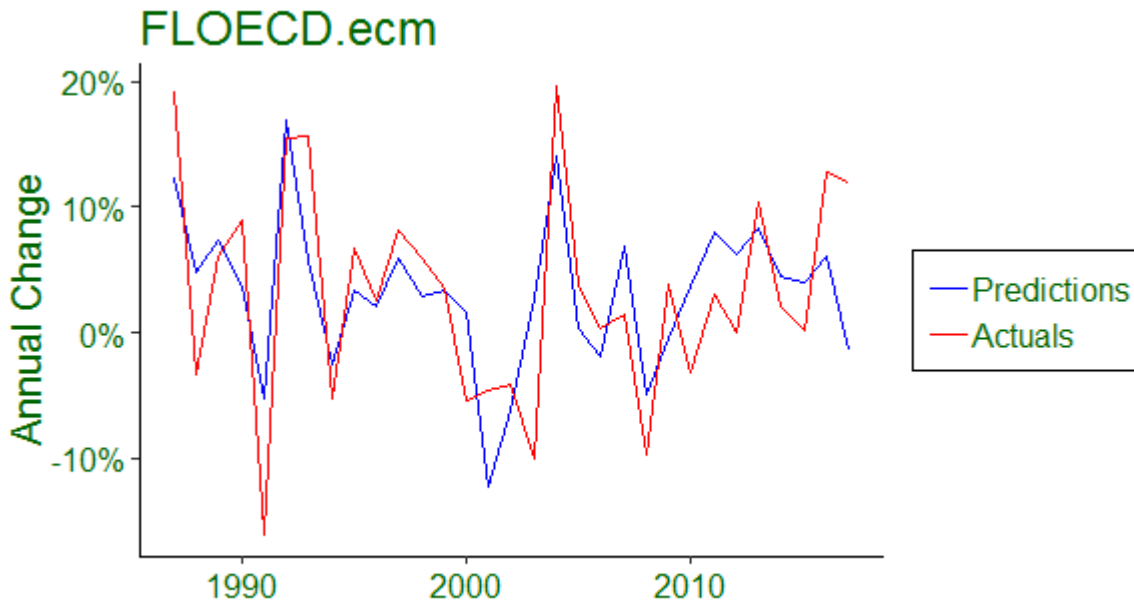
Item	Elasticity	95% Confidence Interval
Fares	-0.1	-0.3 to 0

<sup>14</sup> The compound annual growth rate (CAGR) is the annualized average rate of traffic growth between the beginning and ending years, assuming the same growth rate takes place on an exponentially compounded basis.

OECD GDP	1.1	1.0 to 1.3
----------	-----	------------

### Model fit

3.73 The model predicted changes against actuals over time are plotted below:



### Conclusion and interpretation of model

3.74 The FLOECD model appears to provide credible results, but there are important caveats to note:

- the model passes most of the appropriate statistical tests (but may suffer from second order autocorrelation)
- there is strong evidence to suggest the data are cointegrated
- there is a plausible GDP elasticity

3.75 Although it is encouraging that the model results in a plausible GDP elasticity, the resulting unrealistic fares variable is cause for concern. This may be down to the fares data being based on prices paid by UK residents. It is surprising not to find a statistically significant elasticity for a leisure market. Despite it not being statistically significant, it is retained because it is of the intuitive sign and we would expect it to play a role. The GDP elasticity falls to 1 if the fares variable is removed.

### Foreign Leisure to Rest of the World (FLRoW)

#### Econometric model output in R

3.76 The estimation results of the preferred econometric model are shown below:

## Econometric Models to Estimate Demand Elasticities for the National Air Passenger Demand Model

```
> summary(FLRoW.ecm)
```

```
Time series regression with "ts" data:  
start = 1987, End = 2017
```

```
Call:  
dynlm(formula = d(FLRoW.tra, 1) ~ 0 + +d(FLRoW.AVEGDP, 1) + d(FLRoW.EXR,  
1) + d(FLRoW.FARE, 1) + L(FLRoW.AVEGDP, 1) + L(FLRoW.EXR,  
1) + L(FLRoW.FARE, 1) + d1993 + d1994 + +dPOST2000 + L(FLRoW.tra,  
1), data = data2019m)
```

```
Residuals:  
    Min       1Q   Median       3Q      Max  
-0.07106 -0.02541  0.00000  0.01984  0.07498
```

```
Coefficients:  
              Estimate Std. Error t value Pr(>|t|)  
d(FLRoW.AVEGDP, 1)  2.44325    0.66201   3.691  0.00136 **  
d(FLRoW.EXR, 1)    -0.16089    0.15388  -1.046  0.30764  
d(FLRoW.FARE, 1)  -0.23660    0.09736  -2.430  0.02414 *  
L(FLRoW.AVEGDP, 1)  0.67916    0.23213   2.926  0.00808 **  
L(FLRoW.EXR, 1)   -0.24380    0.08408  -2.900  0.00857 **  
L(FLRoW.FARE, 1)  -0.12735    0.03836  -3.320  0.00326 **  
d1993              0.55915    0.04544  12.306 4.57e-11 ***  
d1994             -0.33642    0.07757  -4.337  0.00029 ***  
dPOST2000         -0.05884    0.02986  -1.971  0.06207 .  
L(FLRoW.tra, 1)   -0.32996    0.13830  -2.386  0.02654 *  
---  
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

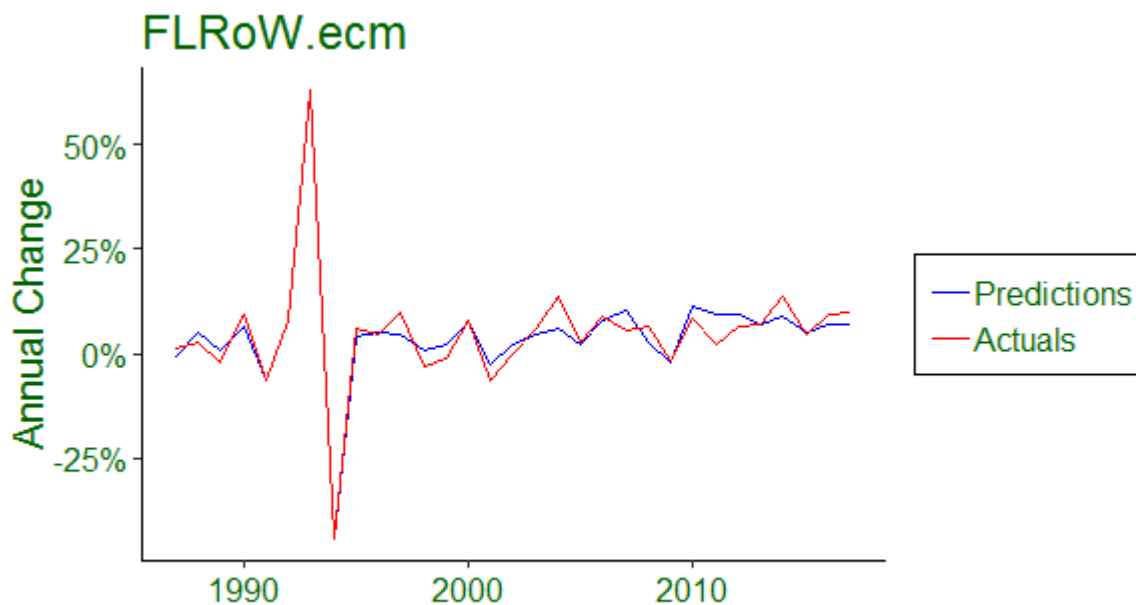
```
Residual standard error: 0.038 on 21 degrees of freedom  
Multiple R-squared:  0.9587, Adjusted R-squared:  0.939  
F-statistic: 48.76 on 10 and 21 DF, p-value: 2.945e-12
```

3.77 This results in the following estimated long run elasticities:

Item	Elasticity	95% Confidence Interval
Fares	-0.4	-0.6 to -0.1
Average of UK / FLRoW GDP	2.1	1.6 to 2.5
Exchange rates	-0.7	-1.1 to -0.3

### Model fit

3.78 The model predicted changes against actuals over time are plotted below:



## Conclusion and interpretation of model

- 3.79 The FLRoW model provides credible results, but there are important caveats to consider. In particular, it is unclear whether cointegration exists according to the bounds test. Furthermore, the Reset test was not passed, and this has not been resolved. On the plus side, other diagnostic tests were passed.
- 3.80 Each elasticity looks plausible. The fares elasticity is on the inelastic side, but as noted elsewhere we have reasons to believe this elasticity is biased towards zero.
- 3.81 The GDP variable elasticity is high; this is unsurprising given traffic growth has averaged 5% (CAGR) since 1986, and traffic growth has been strong despite the rising value of the pound over most of this period.
- 3.82 The exchange rate elasticity is negative despite this variable rising over time (that is, the pound has strengthened against this basket of currencies), as has traffic growth – this provides evidence that the exchange rate effect is genuine.

## UK Business Domestic (UBD)

### Econometric model output in R

3.83 The estimation results of the preferred econometric model are shown below:

```
Time series regression with "ts" data:
Start = 1993, End = 2018

Call:
dynlm(formula = d(UBD.tra, 1) ~ 0 + d(GDP, 1) + L(d(GDP, 1),
  1) + d(UBD.FARE, 1) + L(GDP, 1) + L(UBD.FARE, 1) + dPOST2006 +
  L(UBD.tra, 1) + L(d(UBD.tra, 1), 1), data = dataframe_ts)

Residuals:
    Min       1Q   Median       3Q      Max
-0.049096 -0.016325  0.000628  0.021228  0.055250

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
d(GDP, 1)         1.53118    0.55905   2.739  0.01349 *
L(d(GDP, 1), 1)   1.94511    0.56466   3.445  0.00289 **
d(UBD.FARE, 1)   -0.01344    0.08394  -0.160  0.87462
L(GDP, 1)         0.23824    0.06631   3.593  0.00208 **
L(UBD.FARE, 1)   -0.03294    0.03508  -0.939  0.36024
dPOST2006        -0.10964    0.03334  -3.289  0.00408 **
L(UBD.tra, 1)    -0.20741    0.05461  -3.798  0.00132 **
L(d(UBD.tra, 1), 1) -0.35747    0.16918  -2.113  0.04883 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

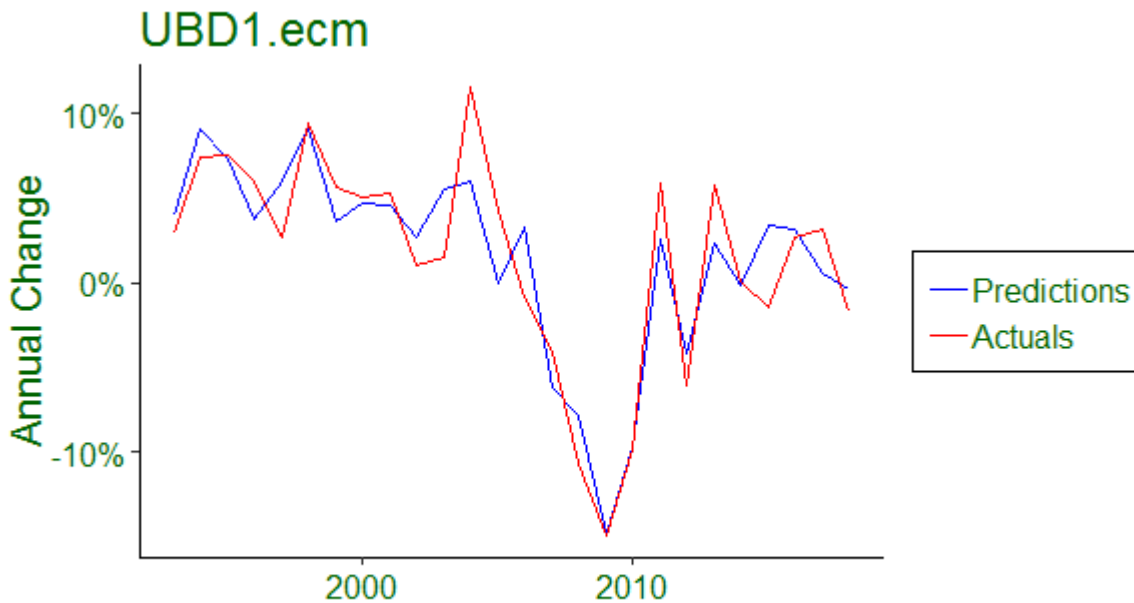
Residual standard error: 0.03182 on 18 degrees of freedom
Multiple R-squared:  0.8301,    Adjusted R-squared:  0.7545
F-statistic: 10.99 on 8 and 18 DF,  p-value: 1.582e-05
```

3.84 This results in the following estimated long run elasticities:

Item	Elasticity	95% confidence interval
GDP	1.149	0.83 to 1.47
Fare	-0.16	-0.50 to 0.18

### Model fit

3.85 The model predicted changes against actuals over time are plotted below:



### Conclusion and interpretation of model

3.86 The UBD model appears to be robust and provide credible results:

- the key long run GDP variable is statistically significant and the sign and magnitude of the fares variable are plausible
- apart from some issues with autocorrelation, the model passes the relevant diagnostic tests
- there is evidence that the data are cointegrated.

3.87 GDP has an estimated elasticity of 1.1 with a 95% confidence interval of 0.8 to 1.5. This elasticity seems plausible, and is significant at the 1% level.

3.88 The fares elasticity is not statistically significant, but the elasticity of -0.2 is plausible. Although we would not expect business passengers to be particularly price sensitive, we would have thought fares would be a driver, so this is slightly surprising. However, the fare variable has been included because we believe that in reality, fares are a key driver of aviation demand.

### UK Leisure Domestic (ULD)

#### Econometric model output in R

3.89 The estimation results of the preferred econometric model are shown below:

## Econometric Models to Estimate Demand Elasticities for the National Air Passenger Demand Model

```
> summary(ULD1.ecm)
```

```
Time series regression with "ts" data:  
Start = 1992, End = 2018
```

```
Call:  
dynlm(formula = d(ULD.tra, 1) ~ 0 + d(GDP, 1) + d(ULD.FARE, 1) +  
L(GDP, 1) + L(ULD.FARE, 1) + L(RAILPPM, 1) + d2001 + d2010 +  
d2011 + L(dPOST2000XGDP, 1) + L(ULD.tra, 1), data = dataframe_ts)
```

```
Residuals:  
      Min       1Q   Median       3Q      Max  
-0.056820 -0.008534  0.000000  0.008203  0.048760
```

```
Coefficients:  
              Estimate Std. Error t value Pr(>|t|)  
d(GDP, 1)         1.01449   0.42165   2.406 0.027786 *  
d(ULD.FARE, 1)    -0.40371   0.11932  -3.383 0.003533 **  
L(GDP, 1)          0.96640   0.15059   6.417 6.38e-06 ***  
L(ULD.FARE, 1)    -0.32616   0.13763  -2.370 0.029898 *  
L(RAILPPM, 1)     -0.30614   0.17229  -1.777 0.093495 .  
d2001             -0.10454   0.03786  -2.761 0.013350 *  
d2010             -0.12648   0.03386  -3.736 0.001645 **  
d2011             -0.07556   0.03220  -2.347 0.031325 *  
L(dPOST2000XGDP, 1) -0.61850   0.14587  -4.240 0.000552 ***  
L(ULD.tra, 1)     -0.33816   0.06453  -5.240 6.65e-05 ***  
---  
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

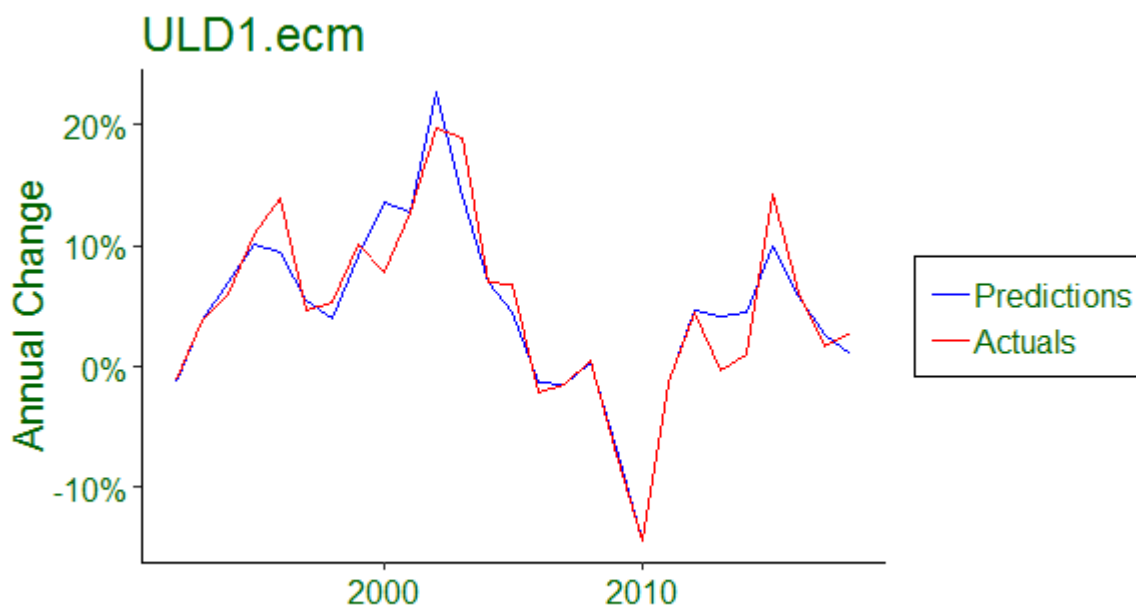
```
Residual standard error: 0.02982 on 17 degrees of freedom  
Multiple R-squared:  0.9289,    Adjusted R-squared:  0.8871  
F-statistic: 22.21 on 10 and 17 DF,  p-value: 7.989e-08
```

3.90 This results in the following estimated long run elasticities:

Item	Elasticity	95% confidence interval
GDP (pre-2001)	2.86	2.34 to 3.37
GDP (post-2000)*	1.03	0.09 to 1.97
Fare	-0.96	-1.66 to -0.27
Rail PPM	-0.91	-1.96 to 0.15

### Model fit

3.91 The model predicted changes against actuals over time are plotted below:





## Conclusion and interpretation of model

3.92 The ULD model appears to provide credible results:

- the model appears to be a good fit
- the variables are significant, of the correct sign and of plausible magnitude
- the model passes the relevant diagnostic tests
- there is evidence that the data are cointegrated.

3.93 The elasticity for GDP (pre-2001) seems unusually high, but the GDP post-2000 elasticity looks much more plausible.

3.94 The rest of the key drivers are all statistically significant, of the correct sign and of plausible magnitude.

3.95 The fares variable is elastic which is to be expected from a leisure market. The rail public performance measure (PPM)<sup>15</sup> variable can be interpreted as a measure of trains' punctuality so the inverse relationship suggests that if trains are delayed, people will prefer to travel by air.

---

<sup>15</sup> An industry standard measure of punctuality, as the percentage of trains that arrive at their terminating station on time. It considers trains to be punctual if they are within five minutes for short-distance, or ten minutes for long-distance, of the planned schedule at their destination.

# Annex A: Peer Review of the Econometric Analysis

## AVIATION DEMAND PEER REVIEW, 2020

### FINAL REPORT 31.01.20

Dr. A. S. Fowkes, Visiting Reader, Institute for Transport Studies, University of Leeds, subsequently Visiting Professor, University of Rome TRE.

#### **Background.**

This document reports my findings from a peer review exercise conducted for Aviation Appraisal and Modelling (AvAM), the Department for Transport. The Department can provide further details on request. The reviewed work updates the DfT's international aviation econometric models that feed into the DfT's National Air Passenger Demand Model (NAPDM). The then current forecasts, published in 2017, used unrestricted error correction models (UECM) estimated with data from 1986 to 2008, for 19 'markets'. When data up to 2017 became available, it was felt worthwhile to re-estimate the models in house, using the existing methodology. Dr Phill Wheat was appointed as adviser. At the time of this review, the models for 3 markets had not been updated, these being two relating to domestic end to end travel and another relating to international to international travel. This report peer reviews the DfT's work in estimating models for the remaining 16 markets, as reported in "191016 Technical Documentation".

My Remit was as follows:

"The peer reviewer will review the econometric analysis we have undertaken, providing advice as to whether it is fit for purpose, focussing on the methodology. In places, we have proposed overrides to the econometrically estimated (long-run) elasticities, and the reviewer's thoughts on these overrides is also in scope. The output will be a short note documenting the reviewer's conclusions."

I have looked at and probed the methodology in considerable detail. Essentially, first differences in traffic is modelled with an error correction term using Ordinary Least Squares (OLS). I am satisfied that current state-of-the-art practice has been followed. In doing that, in my opinion, the chosen estimation equations are under-identified, such that there are more estimated coefficients than model parameters. However, by comparison with the 'partial adjustment model' and a very simple model, I am completely satisfied that the required long run elasticities have been well estimated. Since these drive the forecasts, all is well with them too. I do not believe better elasticity estimates could have been obtained within the current form of modelling and resource availability.

Due to the small number of years of data, with current 'market' models having only some 22 degrees of freedom, the models are currently not strong enough for direct use in forecasting. Were there to be a major review of methodology for a future update, both Dr. Wheat and myself have, independently, advised that it might be worthwhile to look into the 'combined time series and cross section' method (also known as 'panel'). Since data on (at least) 16 'markets' is available, the combined model would be run on 16 times as many data points. That might, however, still be insufficient to estimate a model that was strong enough to be used in direct forecasting, so the effort involved might not prove worthwhile.

It is fortunate, therefore, that I have found the indirect method of estimating elasticities for key drivers, and applying these elasticities to forecasts of those drivers, to be sufficiently robust to forecast future air traffic. This is analogous to the method used to forecast rail traffic in the Passenger Demand Forecasting Handbook. I have checked the method by which the narrow confidence intervals have been obtained, and have found no problem. I looked for attempts to estimate models with non-constant elasticities, but have read that the previous study looked into that and found it infeasible.

Correctly applying precisely estimated elasticities (for various forms of GDP, Fares, and Exchange Rates) to percentage changes in those drivers compared to a base year, without any adjustment for short run effects, should give reliable percentage change forecasts for traffic. However, special attention should be paid to parameter changes in later years, for example post financial crisis. I was surprised that 'constant' terms had not been included, but was assured they had been tried but found non-significant. I am concerned that shortage of degrees of freedom may have prevented the estimation of separate pre- and post-crash elasticities for all 3 drivers and trend growth, and shortage of time may have prevented separate models for all break points (eg 2007, 2008, 2010 etc.) being run.

I have briefly looked at the models for all 16 markets, and have found nothing obviously wrong. Two markets did not have preferred models, and in line with my overall impressions I would suggest trying radically simpler models in those cases, even to the point of ignoring autocorrelation and cointegration concerns if necessary. For the 14 preferred models, graphical presentations have been given of the comparison of the levels for actuals with predictions derived as cumulative differences. Interpretation of these graphs is subjective and disputed, but I count 6 of the 14 showing excesses of predictions (over actuals) in many of the later years (with 3 cases of underpredictions and 5 cases of little difference). This arises as OLS has been applied to first differences rather than levels. I have expressed my preference

for the models to be tweaked to avoid these continuing overpredictions, even if the effect is only aesthetic.

I have looked in greater detail at the ULSE and ULOECD models, with considerable correspondence with the appropriate DfT official, Steve Prichard, who was always helpful and tolerant of my attempts to find fault. In the end, I have found no errors. I further asked for a combined model run on all UK Leisure traffic. This required some compromises but fitted very well. Indeed, a very simple model also fitted very well. It is the way that different model forms all return the same answer that gives confidence that the estimates are trustworthy. To some extent it also suggests that the Department's modelling is somewhat over-elaborate in terms of the requirement for parameter estimation accuracy, though it is justified in wanting to be seen to be at the leading edge of modelling. To be clear, I would have been satisfied with something slightly simpler. For example, I was never convinced that autocorrelation was a serious problem (in this study using annual data). By simplifying in some aspects it might become possible to cope with the introduction of other complexities, such as non-constant elasticities, as well as estimating acceptable models for the 2 markets for which this has not hitherto proved possible.

Once the elasticity estimates have been obtained they are, in some cases, subjected to a series of "over-rides". I have no objection to this in principle. One should not blindly use obviously incorrect values just because a, possibly faulty, model produces them. There is obviously objection if the "over-rides" appear arbitrary. The Department's documentation explains why the "over-rides" were made. Primarily, some fares elasticities have been raised where it was felt that fares (used in the modelling) had been depressed over time as the 'quality of the offer' was reduced; for example by budget airlines not providing food, generous baggage allowances, or a landing in the destination country. I find this quite plausible but feel that judging how big an allowance to make for this was essentially arbitrary. The Department intend to seek better fares data in future, and I further suggested that the Office of National Statistics might be able to advise on how to adjust for 'product quality' in this case.

In terms of reporting, both in terms of what should be reported and how to arrange it clearly, I made several suggestions, listed here in no particular order. Firstly, I suggested improvements to the mathematical presentation of the general model used. Secondly, probably just for one market, I suggested showing an audit trail of how the preferred model came to be chosen. Thirdly, I suggested discussing what was being gained by added complexity relative to a simpler model; in other words, was a statistically significant improvement to a model of sufficient actual value to outweigh the greater complexity. Fourthly, I urged the presentation of Confidence Intervals for the elasticity estimates wherever possible.

---

<sup>i</sup> UK aviation forecasts 2017 - GOV.UK ([www.gov.uk](http://www.gov.uk)):

[https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/878705/uk-aviation-forecasts-2017.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/878705/uk-aviation-forecasts-2017.pdf)

<sup>ii</sup> Re-estimating the National Air Passenger Demand Model Econometric Equations (2011):

[https://webarchive.nationalarchives.gov.uk/ukgwa/20181210012931/https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/4512/re-estimating-napdmee.pdf](https://webarchive.nationalarchives.gov.uk/ukgwa/20181210012931/https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/4512/re-estimating-napdmee.pdf)

<sup>iii</sup> Enders (2004), *Applied Econometric Time Series*, Wiley Series in Probability and Statistics, John Wiley & Sons, Inc., Hoboken.

<sup>iv</sup> Giles (2012), *Integrated & Cointegrated Data* (blog post), available at:

<https://davegiles.blogspot.com/2012/06/integrated-cointegrated-data.html>

<sup>v</sup> Hendry, *Econometrics – Alchemy or Science?*, *Economica*, New Series, Vol 47, No. 188, November 1980

<sup>vi</sup> See Giles (2013), *ARDL models – Part II – Bounds Tests* (blog post), available at:

[https://davegiles.blogspot.com/2013/06/ardl-models-part-ii-bounds-tests.html?sm\\_au=iVVF21J05Q2tRMPr](https://davegiles.blogspot.com/2013/06/ardl-models-part-ii-bounds-tests.html?sm_au=iVVF21J05Q2tRMPr)

<sup>vii</sup> [https://webarchive.nationalarchives.gov.uk/ukgwa/20181210011903/https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/223839/aviation-forecasts.pdf](https://webarchive.nationalarchives.gov.uk/ukgwa/20181210011903/https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/223839/aviation-forecasts.pdf)

<sup>viii</sup> Pesaran, M. H. and Y. Shin (1999), *An autoregressive distributed lag modelling approach to cointegration analysis*. Chapter 11 in S. Strom (ed.), *Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium*. Cambridge University Press, Cambridge.

<sup>ix</sup> Pesaran, M. H., Shin, Y. and Smith, R. J. (2001). *Bounds testing approaches to the analysis of level relationships*. *Journal of Applied Econometrics*, 16, 289–326.

<sup>x</sup> Giles (2013), *ARDL models – Part II – Bounds Tests* (blog post), available at:

[https://davegiles.blogspot.com/2013/06/ardl-models-part-ii-bounds-tests.html?sm\\_au=iVVF21J05Q2tRMPr](https://davegiles.blogspot.com/2013/06/ardl-models-part-ii-bounds-tests.html?sm_au=iVVF21J05Q2tRMPr)

<sup>xi</sup> Smyth and Pearce (2008), *Air Travel Demand*, IATA Economics Briefing No. 9, 2008.

<sup>xii</sup> Re-estimating the National Air Passenger Demand Model Econometric Equations (2011):

[https://webarchive.nationalarchives.gov.uk/ukgwa/20181210012931/https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/4512/re-estimating-napdmee.pdf](https://webarchive.nationalarchives.gov.uk/ukgwa/20181210012931/https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/4512/re-estimating-napdmee.pdf)