To	ORR	**Technical Note**	
Cc	Revenue sub-group of the Schedule 4 & 8 passenger recalibration working group		
From	Steer		
Date	15 May 2023		
Project	Review of the available evidence about the passenger demand response to rail disruption	Project No.	24420401

Recommendations Note

Introduction

1. In response to a request from ORR, this note forms the recommendations from the Steer (and John Bates) team for elasticities to be used for PR23 Schedule 8 recalibration work, based on a review of the recent available evidence about the passenger demand response to rail disruption.

Objective

2. To recommend the preferred econometric evidence to use as an input to the calculation of Network Rail Payment Rates as part of the PR23 passenger Schedule 8 recalibration.

Summary of recommendations

3. The values recommended by this review are shown in Table 1.

Table 1: Recommended Values

	Non-Season	Season
London TCA	-0.022	-0.018
Airport	-0.012	-0.010
London Long Distance [LDL]	-0.009	-0.007
Non-London Long-distance [LDNL]	-0.008	-0.008
Non-London Short-distance [SDNL]	-0.006	-0.002
SE not London [SENL]	-0.018	-0.018
SE to/from London [SEL]	-0.013	-0.010

4. The findings of this note have been discussed at some length with the PR23 Schedule 4 and 8 revenue sub-group. In some areas the recommendations have been based on a combination of evidenced-based analysis and the application of professional judgement in order to deliver a pragmatic, consistent set of results that the full sub-group is able to sign up to.

5. The note has been structured as follows:

- A summary of the recent research developments in this area;
- Detailed results from the most recent studies; and
- Concluding with a justification for the derivation of the recommended elasticities shown above.

Research background

6. This section sets the scene by giving a brief summary of the evidence underpinning the recent developments in research in this area. It partly draws on material prepared by Steer in 2017 for the peer review of Oxera (2017) described below.

Leading up to PDFH 6

7. PDFH v5.1 and previous versions of PDFH set out an approach based on the valuation of delay minutes as a multiple of in vehicle time minutes, based on Stated Preference research, and known as the indirect PDFH approach. As part of the PDFH v5.1 update (which also coincided with the PR13 recalibration of Schedule 8) Wardman and Batley were commissioned to undertake the so-called "**Reliability Review**" (2013). This was a rigorous review and reconciliation of GB evidence on valuations and elasticities of demand with respect to punctuality and reliability. This review recommended, on balance, the retention of the indirect-PDFH approach for that version of PDFH.

8. However, Wardman and Batley went on to author the so-called the **Wardman and Batley** paper[1] which set out a strong case for the use of "Direct PDFH approach". This approach recommended a set of constant elasticities to be applied directly to APM to predict the change in demand. The paper described an extensive review of reliability parameters and comparisons of different approaches and parameters. It concluded that the implied lateness elasticities recommended in PDFH v5.1 were substantially greater than those directly estimated and pointed to the need for additional research. In particular, the paper pointed to exaggerated late time multiplier valuations derived from Stated Preference research.

9. The **PDFH 6 update** team (which included Profs Wardman and Batley) took the use of the Direct-PDFH approach forward, together with input from other studies and stakeholders and, in a working note concluded that the Direct-PDFH approach should be adopted by PDFH6, with elasticities as now set out in PDFH6 Table B5.1, as shown below in Table 2. It is worth noting here that Season elasticities are around 15% lower than for Non-Seasons. This paper also went on to note potential problems with the use of a constant elasticity in this context, where changes in APM can be proportionately extremely large, particularly where performance is already good.

Table 2: Presentation of PDFH6 performance elasticities in consistent format

	Non-Season	Season
London TCA	-0.085	-0.070
Airport	-0.245	n/a
London Long Distance [LDL]	-0.115	-0.100
Non-London Long-distance [LDNL]	-0.115	-0.100
Non-London short-distance [SDNL]	-0.115	-0.100
SE not London [SENL]	n/a	n/a
SE to/from London [SEL]	-0.085	-0.070

Around the time of PR18

10. In **2017 Oxera** reported[2] on its study for PDFC with the objective to investigate the "direct relationship between unplanned service disruption and train operator revenue, focussing in particular on London

[1] Wardman M and Batley R, Travel time reliability: a review of late time valuations, elasticities and demand impacts in the passenger rail market in Great Britain, Transportation, 2014

[2] Oxera and Winder Phillips, The impact of unplanned disruption on train operator revenue, August 2017

commuter services." Steer undertook the peer review of that study later that year. The outcomes of these were:

- The relationship between unplanned disruption and TOC revenue is best modelled using a Direct approach using a semi-elasticity of **revenue** with respect to APM. The study team concluded that revenue, rather than demand, was the preferred dependent variable, although the peer review concluded that there was little evidence for this since both dependent variables delivered similar results.
- Partly because of the use of a Direct approach and a semi-elasticity, but also because of the size of the estimated coefficients, this relationship was less sensitive than that adopted using the Indirect PDFH approach in PDFH v5.1
- The Peer Review team were able to undertake additional analysis which provided disaggregation of the single elasticity reported by Oxera, by ticket type and by two PDFH market segments: London TCA and South East to/from London.
- The relationship is dynamic, but with a lag of less than a year.

11. It Is worth noting that this research was being undertaken at the same time as a consensus of the final content of PDFH6 was being reached[3]. As such, those formulating an approach for PR18 Schedule 8 noted the potential difficulties with the PDFH6 constant elasticity approach and the benefits of the use of semi-elasticities. Therefore, the approach adopted for Schedule 8 recalibration was to adopt the Indirect PDFH approach (as used for the previous Periodic Review) combining delay multipliers, GJT and GJT elasticities, except where the Oxera approach using semi-elasticities was available (London TCA and SEL). The values used for PR18 are summarised in Table 3. In this case the evidence for higher sensitivity for non-season ticket holders is more mixed, particularly outside London.

Table 3: Recommended values used in PR18 Schedule 8 payment rates

Flow Group Semi-elasticities	Full	Reduced	Season
London TCA	-0.1133	-0.0645	-0.0437
SE to/from London	-0.0205	-0.0305	-0.0210
Delay multipliers	**Non-Commuting**		**Commuting**
London Long Distance	3.0		2.5
Non-London > 20 miles	3.4		3.9
Non-London <=20 miles	2.3		3.0
SE Outer Suburban	2.3		2.5
Airport	6.0		

Recent research

12. Since the PR18 recalibration there have been two studies to report significant results in this area. Results for these studies have been included in the following section.

13. The first, referred to as **Steer (2019)**[4], was intended to extend the Oxera approach to provide full national coverage, which it did to some extent, although statistically significant results could not be obtained for all segment and ticket type combinations. However, the analysis also exposed an inconsistency between the performance data collated for the study and that for Oxera's study, whereby the latter data overinflated the (DML) cancellation component of APM. It was strongly suggested that this had resulted in semi-

[3] PDFH 6 was eventually published in May 2018

[4] Impact of Unplanned Disruption on Train Operator Revenue: Extension of Geography, March 2019

elasticities that were too high. The reported semi-elasticities in the Steer (2019) analysis were generally lower.

14. The **Systra (2022)** study set out to further develop the evidence base for the semi-elasticity approach by considering planned disruption and possible non-linearity for larger changes in performance: this has recently been the subject of a Peer Review by Steer. After correcting for some similar issues with the performance data to that experienced by Oxera, the revised report provided a comparable range of significant semi-elasticities to the Steer (2019) report. While the peer review was broadly supportive of the **econometric analysis**, it was concerned that there was very little supporting evidence for moving from the initial, simple model form to the more complex models preferred by Systra, including disaggregation of demand and performance data and additional exogenous variables – this appeared to be a hangover from the logic adopted prior to the correction of the data.

15. The Systra (2022) study also included a **meta-analysis** based on the results of all previous research in this area, an update of the work described above by Wardman and Batley. While this does not feed directly into the econometric research, there was an expectation that this could provide a source for infilling recommended semi-elasticities where the econometric analysis was not fruitful.

Results from recent research

Steer (2019)

16. Steer (2019) estimated semi-elasticities for 7 flow groups and 3 ticket types, using data covering 5 years (2013/14 P2 to 2017/18 P13). Essentially the same model formulation as Oxera (2017) was used (although the data was different), and can be written:

$$log(\text{Revenue}_{i,t}) = \alpha.log(\text{Revenue}_{i,t-1}) + \gamma.APM_{i,t} + \eta_i + \delta_t + \varepsilon_{i,t} \qquad (1)$$

17. where:

- i is flow and t is time period/year combination
- α is the coefficient on the lagged revenue term, a relatively simple dynamic model specification, whereby the impact on a single period's revenue influences the following periods' revenue, reducing over time (assuming α < 1).
- γ is the coefficient on the AML term and represents the short term semi-elasticity to revenue.
- η is the first part of a two-way fixed effects, used to isolate trends across flows.
- δ is the second part of a two-way fixed effects, explaining time series effects not related to APM.
- ε is the remaining error term.

18. The long-run semi-elasticity is given by the formula γ /(1 – α).

19. The estimated long-run semi-elasticities are shown in Table 4 (taken from Table 4.3 of the Steer report, supplemented with more detailed information on t-statistics [5]).

[5] NB The t-statistics quoted relate to the short-run semi elasticity γ. Strictly speaking the corresponding t-stats for the long-run should be calculated using an approximate formula for its variance of $\frac{1}{(1-\alpha)^2}.var(\gamma) + 2\frac{\gamma}{(1-\alpha)^3}.cov(\gamma,\alpha) + \frac{\gamma^2}{(1-\alpha)^4}.var(\alpha)$. We have not been able to verify whether this was done for the Steer (2019) work. However, the t-statistics for the α parameter are so high that it is acceptable to take the short run t-statistics as being adequately representative.

Table 4: Long run (LR) semi-elasticity (APM min) from Steer (2019) Table 4.3

	Full [F]		Reduced [R]		Seasons [S]	
	value	t-stat (SR)	value	t-stat (SR)	value	t-stat (SR)
London TCA	-0.0200**	–2.00	-0.0249*	–1.92	-0.0143	–0.81
Airport	-0.0234	–1.89	-0.0228*	–1.95	-0.0279	–1.57
London Long Distance [LDL]	-0.0012	–0.37	-0.0095***	–4.55	-0.0148	–1.36
Non-London Long-distance [LDNL]	-0.0113***	–3.62	-0.0196***	–4.37	-0.0157***	–3.09
Non-London short-distance [SDNL]	-0.0487***	–2.90	-0.0446***	–2.72	-0.0062	–1.25
SE not London [SENL]	-0.0144***	–5.38	-0.0228***	–6.63	-0.0178***	–3.43
SE to/from London [SEL]	-0.0128***	–2.73	-0.0131	–1.64	0.0054	n/a

Three asterisks indicate that the relationship was statistically significant from zero at the 99% confidence interval, two asterisks at the 95% confidence interval and one at the 90% confidence interval. Values shown in red are wrong-sign.

20. With the exception of SEL Season tickets, all elasticities have the correct negative sign, but only 15 are significant at at least the 90% level, the range is generally between –0.01 and –0.025: only SDNL has larger values (around –0.04) for Full and Reduced tickets. Given the relatively low t-ratios, it is worth noting that not all the estimated semi-elasticities are significantly different from each other. For the right sign estimates, pair-wise comparisons revealed that:

- within flow groups, significant distinctions between ticket types were found only for:
  - LDL (where R*** > F) and
  - SDNL (where F*** and R*** > S);
- within ticket types, significant distinctions between flow groups were found only for:
  - Full: SDNL*** > SEL***, SENL***, LDNL*** > LDL.
  - Reduced: SENL***, SDNL*** and LDNL*** > LDL***.
  - Seasons no distinctions.

21. This suggests prima facie that it will be difficult to recommend separate values for each of the flow groups ticket type combinations. There is some indication that LDL values are smallest, and SDNL values are largest.

22. We should note that the flow groups were essentially specified in the requirements for the Steer (2019) "Extension of Geography", and are based on RUDD station definitions. They are broadly consistent with PDFH, with the addition of the SENL segment.

Systra (2022)

23. The Systra (2022) report adopts essentially the same model specification, and covers the same flow groups, with the exception of London TCA[6]: the data relates to seven years from RY2013 to RY2019. The same assumption about t-stats and the relative levels of significance is made as in the Steer work. In considering a reconciliation of results, the essential question with regard to Systra (2022) is: which of the reported models to use?

24. The first reported models are set out in Table 17, as summarised in Table 5. At the 95% significance level there are 7 significant estimates (out of a maximum of 21) and they are generally half the size of the equivalent values in Steer (2019).

[6] In the report it is not made clear why London TCA has been excluded, which is particularly conspicuous as the study was intended to 'devote particular attention to… ' '…commuters in London…'.

Table 5: Long run (LR) semi-elasticity (APM min) from Systra (2022) Table 17

	Full [F]		Reduced [R]		Seasons [S]	
	value	t-stat (SR)	value	t-stat (SR)	value	t-stat (SR)
London TCA	n/a					
Airport	-0.0015	–0.35	-0.0110***	–4.09	0.0000	–0.01
London Long Distance [LDL]	0.0033	n/a	-0.0029	–0.17	0.0015	n/a
Non-London Long-distance [LDNL]	-0.0065***	–5.39	-0.0088***	–8.60	-0.0065***	–2.91
Non-London short-distance [SDNL]	-0.0057***	–4.44	0.0013	n/a	-0.0020***	–3.01
SE not London [SENL]	-0.0060	–1.13	-0.0087*	–1.94	-0.0178*	–1.78
SE to/from London [SEL]	-0.0012**	–2.14	-0.0025	–0.70	0.0017	n/a

25. In subsequent tables these models are further developed, initially through a reasonable attempt to match the demand data disaggregated by ticket type with a time of day representation of the APM data, and subsequently by addition of other variables – resulting in preferred models with 95% significant results for 10 segments.

26. Throughout the model development there was very limited improvement in model fit, until at a late stage the APM data distribution was truncated by removing the top 5% of values. Given the impact of this exclusion on the results, the reviewers did not find the explanation for the truncation sufficiently convincing and recommend returning to the original estimates in Table 17, as shown above. In the reviewers' view it would have been preferable to have introduced more aggregation to achieve more robust results, rather than disaggregation.

Combining the studies' results

27. Thus there are two recent studies available for which we have significant results for a reasonable proportion of the flow group / ticket type combinations required: at least one study provides a significant result (at the 95% level) for 13 of the 21 combinations (16 at 90% significance), 5 of which are significant in both studies.

28. We have observed that the estimated elasticities are generally lower from the Systra (2022) study, and it has been suggested that this could be because the data set, assembled for that study from Timings data, has systematically higher APM values than that assembled from Pears for the Steer (2019) study, as illustrated on average in Figure 10 of the final report. In the process of reviewing and revising the Systra performance data (see paragraph 13), an exercise to compare the two data sets at a flow level was undertaken which did highlight some differences, but nothing systematic. In particular, we have not seen any evidence that PEARS data only being available at monitoring points leads to an increase in average APM values. As we have noted, the more significant results in the model preferred by Systra appear to be due to the removal of the highest 5% of APM values. We have not seen what the impact of this might be on the comparison as shown in Figure 10, but it does not result in a consistent increase in the levels of elasticity for all flow groups and ticket types. More analysis to understand differences between the data sets would be welcomed, but is not currently expected to be available.

29. In the absence of more detailed work on the Systra (2022) data set and particularly the exclusion of the largest APM values, we have concluded that the best source of up-to-date semi-elasticity estimates is to combine the results from these two studies, wherever the estimates are of the right sign. This will allow us to retrieve more significant results and take advantage of the cases where both studies have generated useful results.

30. Ignoring cases where a positive result has been estimated, we can take the weighted average of the Steer (2019) and the Systra (2022) results, taking the minimum variance approach. Using this:

the weighted average, $\mu = \alpha.\beta_1 + (1-\alpha).\beta_2$ where $\alpha = \frac{var(\beta_2)}{var(\beta_1)+var(\beta_2)}$ and the combined variance = $\frac{var(\beta_1).var(\beta_2)}{var(\beta_1)+var(\beta_2)}$. Note that the square root of the variance of the individual estimates can be obtained by dividing the coefficients by their t-ratios in the Tables above.

31. This produces the values in Table 6. The highlighted values are either positive or missing in Systra (2022), and so the Steer (2019) value is used directly. No value is available from either study for SEL Seasons.

Table 6: Weighted average semi-elasticities from Steer (2019) and Systra (2022) Table 17 (highlighted values from Steer only

	Full [F]		Reduced [R]		Seasons [S]	
	value	t-stat (SR)	value	t-stat (SR)	value	t-stat (SR)
London TCA	-0.0200**	-2.00	-0.0249*	–1.92	-0.0143	-0.81
Airport	-0.0038	-0.95	-0.0116***	-4.42	-0.0279	-1.57
London Long Distance [LDL]	-0.0012	-0.37	-0.0094***	-4.54	-0.0148	-1.36
Non-London Long-distance [LDNL]	-0.0071***	-6.33	-0.0093***	-9.36	-0.0080***	-3.91
Non-London short-distance [SDNL]	-0.0059***	-4.65	-0.0446***	-2.72	-0.0021***	-3.15
SE not London [SENL]	-0.0127***	-5.31	-0.0176***	-6.44	-0.0178***	-3.86
SE to/from London [SEL]	-0.0014**	-2.45	-0.0043	-1.31	n/a	n/a

32. It is slightly odd that the Airport Full estimate is closer to the Systra result than the Steer. It turns out that despite the very low significance of the Systra value, the variance is smaller than that of the Steer value. While we believe that the minimum variance method is the appropriate way of combining two independent estimates, in applying the method we have accepted all the results from both studies provided the sign is correct. We have found that more consistent results are obtained if we repeat the analysis stipulating a minimum level of statistical significance for inclusion. This minimum level is reliant on the application of professional judgement, but a level of 1.00 has been agreed with the working group.[7] The impact of this change is shown in Table 7 highlighted in green and includes LDL Full not having a significant value.

Table 7: Weighted average semi-elasticities from Steer (2019) and Systra (2022) Table 17 (highlighted values from Steer only

	Full [F]		Reduced [R]		Seasons [S]	
	value	t-stat (SR)	value	t-stat (SR)	value	t-stat (SR)
London TCA	-0.0200**	-2.00	-0.0249*	–1.92	-0.0143	-0.81
Airport	-0.0234	-1.89	-0.0116***	-4.42	-0.0279	-1.57
London Long Distance [LDL]	n/a	n/a	-0.0095***	-4.55	-0.0148	-1.36
Non-London Long-distance [LDNL]	-0.0071***	-6.33	-0.0093***	-9.36	-0.0080***	-3.91
Non-London short-distance [SDNL]	-0.0059***	-4.65	-0.0446***	-2.72	-0.0021***	-3.15
SE not London [SENL]	-0.0127***	-5.31	-0.0176***	-6.44	-0.0178***	-3.86
SE to/from London [SEL]	-0.0014**	-2.45	-0.0131	-1.64	n/a	n/a

33. Given these results and the corresponding t-ratios, we can repeat the pairwise comparisons carried out for the earlier Steer results. These reveal that:

[7] While this resolves the Airport Full issue, the same issue occurs with SEL Full, but with both significance levels greater than 95%.

- within flow groups, significant distinctions between ticket types were found only for:
  - SDNL (where R*** > F*** > S***);
- within ticket types, significant distinctions between flow groups were found only for:
  - Full: SENL*** > SDNL***, LDNL*** > SEL*** and SENL***> SEL***.
  - Reduced: SDNL*** > Airport***, LDL***, SEL***, LDNL***, and SENL*** > LDL***, SEL***, LDNL***.
  - Seasons SENL*** and LDNL*** > SDNL***.

34. These results are similar to, but somewhat more significant than, the Steer (2019) only results. They still suggest that not all the distinctions can be maintained. Of the significantly estimated results, two elasticities in particular stand out and we will return to these in the remainder of this note:

- SEL Full appears particularly low, when compared to Steer (2019) and all other elasticity estimates.
- SDNL Reduced appears particularly high, when compared to all other estimates.

Systra (2022) Meta-analysis

35. With this in mind, we can consider whether the meta-analysis provides some further guidance. Firstly, we note that the meta-analysis relates to constant elasticities, while the results reviewed are semi-elasticities. For ease of comparison, we therefore need to convert the semi-elasticities; this can be done crudely by multiplying the semi-elasticities by the average APM for the relevant segment. Given that the APM values by segment should be reasonably comparable between the Steer (2019) and Systra (2022) data, and having access to the former, we have used the Steer (2019) data to generate Table 8.

Table 8: Average APM values by segment over full period of data, Steer (2019)

	Full	Reduced	Non-Season	Season
London TCA	2.40	2.51	2.46	3.50
Airport	3.86	3.68	3.79	3.83
London Long Distance	5.36	5.11	5.14	4.02
Non-London LD	3.23	3.68	3.53	3.08
Non-London SD	2.80	2.87	2.83	2.74
SE not London	2.65	2.84	2.77	2.79
SE to/from London	2.88	3.39	3.23	2.90

36. We have used these values to convert the semi-elasticity estimates in Table 7 to constant elasticities in Table 9, with values highlighted in bold significant at the 95% level.

Table 9: Weighted average converted constant elasticities from Steer (2019) and Systra (2022) Table 17

	Full	Reduced	Season
London TCA	**-0.048**	-0.062	-0.050
Airport	-0.090	**-0.043**	-0.107
London Long Distance [LDL]	n/a	**-0.049**	-0.059
Non-London Long-distance [LDNL]	**-0.023**	**-0.034**	**-0.025**
Non-London short-distance [SDNL]	**-0.017**	**-0.128**	**-0.006**
SE not London [SENL]	**-0.034**	**-0.050**	**-0.050**
SE to/from London [SEL]	**-0.004**	-0.044	n/a

37. The Systra (2022) Meta-analysis note[8] offers alternative sets of results in Table 3.6, depending on the treatment of insignificant results in the meta-analysis dataset. Our choice has been to use LR2, which "uses the meta model's implied late time elasticities for insignificant observations. These are not zero but are only around a quarter of those implied where elasticities are significant at the 10% level." The LR2 results lie within the suggested upper and lower bounds, and Systra expressed a "pragmatic preference for using these". The relevant results corresponding to this are shown in Table 10, compared with the significant elasticities taken from Table 9. In passing, we may note that in our view the Oxera (2017) values should be removed from the meta-analysis, as we have demonstrated (Steer, 2019) that these are based on inconsistent APM data and are too large: this will not affect most of the results, however, since the Oxera (2017) study only related to commuter journeys into London.

Table 10: Comparison of meta-analysis and weighted average constant elasticities

	Non-Season		Season	
	Meta-analysis LR2	**Implied Steer/Systra Elasticity**	**Meta-analysis LR2**	**Implied Steer/Systra Elasticity**
London TCA	-0.154	-0.048 (F)	-0.088	n/a
Airport > 20 miles	-0.066	-0.043 (R)	n/a	n/a
London Long Distance [LDL]	-0.051	-0.049 (R)	-0.029	n/a
Non-London >20 miles [LDNL]	-0.059	-0.023 (F), -0.034 (R)	-0.044	-0.025
Non-London <=20 miles [SDNL]	-0.037	-0.017 (F), -0.128 (R)	-0.031	-0.006
SE not London [SENL]	n/a	-0.034 (F), -0.050 (R)	n/a	-0.050
SE to/from London [SEL]	-0.056	-0.004 (F)	-0.027	n/a

38. The general conclusions of the meta-analysis are that Seasons have a lower elasticity than non-Seasons (the model suggests 28% lower on average). London TCA elasticities are more than double the size of the elasticities for all other segments, which lie between -0.04 and -0.07 for Non-Seasons and -0.03 and -0.04 for Seasons – these high values can also be seen in Table 3 and may be attributed to the issues with the Oxera (2017) data set on which these are based.

39. Where it is possible to compare the constant elasticities with the blended, converted values from Table 10 it is initially reassuring that the elasticities are of a similar order of magnitude around -0.050, with the exceptions being the higher elasticities from the meta-analysis for London TCA (though the meta-analysis appendix suggests that the TCA values reported there "must be treated with some caution") and for SDNL Seasons and SEL Non-Seasons, where the newly estimated values appear particularly low, as highlighted in the table.

40. This suggests that more effort would ideally be needed to derive recommended values. The Steer/ Systra studies cannot generally support the ticket type distinctions, but – on the basis of the meta-analysis results – it is probably worth keeping the Season/non-Season distinction. That implies – ideally – rerunning both studies to combine Full and Reduced tickets (or finding some approximate way of combining them). It would also have been useful to re-run the meta-analysis study based on semi-elasticities (or alternatively, re-running the Steer/ Systra studies using standard elasticities, while establishing more rigorous procedures for moving between the two).

[8] Appendix B to the main Systra (2022) Report

Recommendations

Background

41. The above presents the available evidence from which the recommended values for use in Schedule 8 recalibration will need to be drawn. This section describes the process by which the recommendations have been derived. Firstly, a brief reminder of the sources of this evidence:

- PDFH v5.1 used the indirect PDFH method to estimate the impact of changes in unplanned disruption on demand, converting changes in APM to equivalent GJT using delay multipliers and applying GJT elasticities.
- PDFH6 recommended a set of constant demand elasticities which were to be applied directly to changes in APM, based on a review by Wardman and Batley which included meta-analysis.
- Oxera (2017) produced a set of semi-elasticities which provided a more robust basis for application, but were subsequently shown to be based on data which overestimated the impact of cancellations.
- PR18 Schedule 8 recalibration used a combination of Oxera (2017) for London commuting segments, and PDFH v5.1.
- Steer (2019) built on Oxera (2017) with an attempt to cover all PDFH segments and improved data.
- Systra (2022) included econometric analysis based on similar data, once this had been peer reviewed by Steer and corrected. Steer's peer review of the analysis has a preference for the initial aggregate modelling (referred to as Table 17) over the preferred models which were both more disaggregate and based on an exclusion of 5% of the data.
- Systra (2022) also included a meta-analysis update to the Wardman and Batley paper in terms of direct constant elasticities.

42. For context, and to highlight the areas of most concern, we have also included a summary by segment of the total revenue by ticket type and PDFH segment, as Figure 1. This data is from a pre-Covid year, and the mix will certainly have now changed. In particular we would expect the share of Season tickets to significantly reduce in CP7.

Figure 1: Relative size of market segments by revenue, based on RUDD19 data for 2018-19 (pre-Covid)

		Non Season	Seasons
London TCA		5%	3%
Airport		5%	0%
Long Distance London		27%	1%
Non-London > 20 miles		16%	1%
Non-London < 20 miles		4%	1%
South East not to/from London		3%	1%
South East to/from London		20%	13%

43. Although none of the sets of estimates presented in Table 4, Table 5 and Table 7 in this note from Steer (2019) and Systra (2022) are fully complete, we have confidence in the overall approach using **semi-elasticities** and the order of magnitude of the elasticities in this most recent research, of the order of -0.01. We believe that the evidence suggests this research is more robust and up-to-date than previous attempts to model this relationship. In particular:

- The average modelled demand impact based on these values is somewhat lower than from the semi-elasticity values used for PR18. These were based on the 2017 Oxera work with its data issues and strictly speaking applied to revenue, rather than demand.
- In turn the Oxera values (while not directly comparable) showed less sensitivity of demand to performance changes than the previous GJT approach, also used in PR18.
- The use of semi-elasticities has been demonstrated to be more stable than either constant 'direct' elasticities (as recommended in PDFH 6) or the 'indirect' GJT approach.

- It is also worth pointing out that although our recommendations involve a degree of interpolation between values derived from research, this is common practice in developing PDFH recommendations, and in particular the PDFH v5.1 GJT approach used in PR18.

44. While, as requested, we provide a full set of semi-elasticities as described below, we believe that some **additional analysis** would improve the recommendations. We recognise that these are unlikely to be available in the short timescales that we are working to, and so we have used a simplified method for averaging between, especially, ticket types. In particular:

- We have noted that in the majority of cases the Full and Reduced elasticities are not significantly different from each other, and are recommending a single Non-Season value for each segment. This is based on a simple assumption of equal contribution from each ticket type. A preferable method would be to revisit Steer (2019) and Systra (2022) analysis and re-estimate Non-Season elasticities in each case.
- Similarly in places we have recommended averaging across all ticket types, and we have adopted a similar method in this case.
- As we described above, the meta-analysis has proved less useful than hoped. Part of the reason for this is that it includes elasticities from the Oxera work that has proved to include an inconsistent representation of cancellations, especially in London TCA. But also the quoted elasticities are constant rather than semi. We have attempted to undertake a very simple conversion, but a better comparison might be possible if the above re-estimation of Steer (2019) and Systra (2022) described above, also output constant elasticities. This could make it easier to use the meta analysis to fill in the gaps.

Hierarchy of evidence

45. We have based our recommendations on all of the above evidence as follows:

- Recognising that the most recent and robust results using the recommended semi-elasticity formulation based on the best data sets are from the Steer (2019) and Table 17 of the Systra (2022) studies.
- Combining results from these two studies using the minimum variance method to deliver more robust results and allow for a single result where both studies produce significant results. This has been supplemented by exclusion of estimates for which the t statistic is less than 1.00 – as agreed with the revenue sub-group. We quote recommended elasticities to 3 decimal places, so as not to overstate the confidence in the accuracy of the estimates.
- Noting that for most flow groups Full and Reduced estimates are not significantly different from each other and that previous recommendations have generally been at the Non-Season level, we have used the same minimum variance method to derive single Non-Season estimates. (This has the advantage of reducing the magnitude of the LDNL elasticity from Steer (2019), which had been flagged as being large).
- For Seasons:
  - One flow group (SDNL) has a Season elasticity which is significantly different from the Non-Season.
  - Two flow groups (LDNL and SENL) have Season elasticities which are not significantly different from the Non-Season, but we have chosen to retain the distinction, although for LDNL the values are the same at 3 DP. In the case of SENL this results in a Season elasticity (-0.018) 20% **larger** than the Non-Season (-0.015), which is contrary to the pattern for all other flow groups, once the approach described below has been applied.
  - The remaining four flow groups have insignificant Season elasticities. Here we have drawn on evidence from PDFH6 and the meta-analysis which suggests a lower (15% - 28%) Season elasticity value, compared to the Non-Season value. We have recommended a 20% lower value for these flow groups.

46. That gives a full set of elasticities, but before they are recommended, we have undertaken an internal consistency check using the relative values from PR18 Schedule 8, PDFH6 and the meta-analysis as a frame of reference. The results of this were to note that:

- SEL elasticities are an order of magnitude too low, at -0.001, and this is one of the two most important flow groups. This appears to be driven by the Systra (2022) elasticities from Table 5. Our recommendation for this flow group is to use the Steer (2019) result from Table 4, as it appears more consistent and robust. This means a Non-Season elasticity of -0.013, which in turn gives a Season-elasticity of -0.010, using the 20% rule described above.
- The inconsistency described above for SENL is driven by combination of weak Systra (2022) results with Steer (2019) results. It is also worth noting the relative sample sizes for this flow group, as shown in Table 11. Unlike all other flow groups where the sample sizes are broadly similar, for this flow group the Steer (2019) sample size is 5-6 times larger. An appropriate solution has been agreed to only use the Steer (2019) results for this flow group as well.
- While the SDNL Season elasticity also appears low, although to a lesser extent, this flow group is also less important in revenue terms and both studies give broadly comparable answers. It is also not inconsistent with the higher Non-Season elasticity

Table 11: Sample sizes for two key studies

	Steer (2019)		Systra (2022)	
	Non-Season	Season	Non-Season	Season
London TCA	4,900	4,488	n/a	n/a
Airport	2,293	1,246	3,109	2,057
London Long Distance [LDL]	3,171	840	2,826	1,949
Non-London Long-distance [LDNL]	20,996	9,643	23,989	11,988
Non-London short-distance [SDNL]	8,507	7,198	9,974	9,930
SE not London [SENL]	17,595	12,225	2,786	2,752
SE to/from London [SEL]	8,740	6,945	8,250	8,230

47. The Schedule 8 revenue sub-group had recommended a hierarchy of evidence as follows:

- Parameters to be selected from positively peer-reviewed studies, with emphasis on more recent evidence. At the time this was developed, these were expected to be the Systra (2022) preferred models, Steer (2019) and the meta-analysis.
- Parameters chosen to be significant, with intuitive values.
- The full set of parameters to be self-consistent (e.g. relative sizes across product segments).

48. We believe the hierarchy behind our recommendations is broadly consistent with this, with slight variations:

- We have only positively peer reviewed an earlier version of the Systra (2022) model and given it a status equal to the Steer (2019) values.
- The meta-analysis has been given equal weight with PDFH6 as a source of relative values in order to produce Season ticket elasticities for some flow groups and to facilitate the consistency check referred to in the third bullet.

49. Following this process, our final recommendations are as shown in Table 12.

Table 12: Recommended Values for demand semi-elasticities to changes in APM

	Non-Season	Season
London TCA	-0.022	-0.018
Airport	-0.012	-0.010
London Long Distance [LDL]	-0.009	-0.007
Non-London Long-distance [LDNL]	-0.008	-0.008
Non-London Short-distance [SDNL]	-0.006	-0.002
SE not London [SENL]	-0.018	-0.018
SE to/from London [SEL]	-0.013	-0.010