hs2 engine for growth

THE ECONOMIC CASE FOR HS2

Risk analysis for the HS2 economic case

Technical documentation

October 2013

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Department for Transport

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1 Introduction

1.1 Scope and purpose of this document

1.1.1 This document provides background information and additional technical detail on the analytical techniques that were used to calculate the benefit-cost ratio (BCR) distributions in the October 2013 *Economic Case for HS2*. The BCR is calculated from estimates of transport user benefits, construction and operating costs, fare revenues and monetised externalities following standard procedures and assumptions, as set out in the Department for Transport's WebTAG guidance[1].

1.1.2 Our previous assessments of the economic case have focused on the production of single scenarios, each based on a set of outputs from the PLANET Framework Model (PFM) model. For both Phase One and the full network, one of the scenarios was presented as a 'central case' and, in effect, was 'the BCR' for the scheme.

1.1.3 However, whilst this approach provides a good basis for comparison of proposals, it is ultimately only one view of the future. In an infrastructure project with a potential lifespan of over 100 years, a single point-estimate fails to capture the potential upside and downside risks to returns from the investment.

1.1.4 Therefore, for this update of the economic case, we have adopted a different approach to assessing the strength of the case. This new approach is based on assessing the potential range of returns in a way that allows us to understand the resilience of the returns to a range of different futures.

1.1.5 The assumptions that are made when assessing the returns from transport infrastructure investments, such as the rate of growth in the demand for travel, and the strength of economic growth, can exert a strong influence on the results of the analysis. In order to inform the assessment of the resilience of the economic case we have tested the strength of the case under a wide range of different assumptions.

1.1.6 This document provides an explanation of the analysis techniques that we have used to inform this assessment and the analysis that underpins some of the inputs to the assessment.

1.2 Document structure

1.2.1 The report is presented in 3 parts. This chapter provides a brief overview of the material. Chapter 2 provides an introduction and background to the Risk Analysis Model, and a description of the modelling approach, and Chapter 3 provides detail on the inputs and assumptions.

1.2.2 A glossary of terms is provided at the end of the document.

[1] WebTAG is the Department for Transport's guidance on how to assess the costs and benefits of transport infrastructure/policies. WebTAG sets out the methods and assumptions that the DfT recommends should be used to model the impact of schemes. http://www.dft.gov.uk/webtag/.

2 Our approach to analysing risk

2.1 Introduction

2.1.1 Risk analysis is a technique that can be applied to determine the combined impact of multiple sources of quantifiable risk on an outcome. The approach relies on the definition of ranges of risk around key factors, and the repeated simulation of the impact of different combinations of those factors on the outcome in question. A key advantage of using such an approach is that it guards against excessive weight being placed on extreme outcomes that would require the coincidence of a set of unlikely events to occur.

2.1.2 For this analysis, the key output measure is a benefit-cost ratio of the HS2 proposal calculated from estimates of transport user benefits, construction and operating costs, fare revenues and monetised externalities for many different scenarios. Each simulation has a different set of assumptions which generates a different set of benefits, costs and revenues and hence a different BCR. A probability distribution of BCRs can be generated from the thousands of simulations that have been produced and the likelihood of different value for money outcomes assessed.

2.1.3 A high number of simulations are required to build a reliable distribution of possible outcomes. In order to achieve this, the model that is used to predict the outcome must be capable of being run quickly and automatically. We base the risk analyses for the Economic Case on 2000 simulations for each run. The PFM suite of rail forecasting models used to produce the standard case forecasts and sensitivity tests can take many hours to run. Instead of repeatedly running the PFM model to derive results for each of the simulations, we have developed a more efficient approach, which uses key relationships from PFM to simulate the results for the different scenarios.

2.1.4 The risk analysis approach generates the input values using the Latin-Hypercube method[2] to produce efficient distributions of numbers for use in the simulations. The approach then quantifies the likely variations in the benefit cost ratio (BCR) in response to distributions of inputs by simulating their impact on the profile of the benefit, revenue and cost streams during the construction and operation of the railway.

2.1.5 Some of these variables, e.g. construction costs, are a direct input to the calculation of the BCR. Others, such aseconomic growth or demand elasticities influence the BCR via their relationships with demand and the monetary values that are placed on the benefits.

2.2 Estimating changes in benefits in response to changes in rail demand

2.2.1 Ordinarily, when conducting an appraisal of a transport infrastructure investment, the transport planning model (in our case, PFM) is run twice – once with, and once without

[2] The Latin Hypercube method is a stratified sampling method that allows the accurate generation of a realistic probability distribution.

the investment (in this case HS2) – for each of two or more forecast years. The benefits and revenues for each of the modelled years can then be calculated by comparing the outputs from the model (demand, travel times, crowding etc.) for each of those scenarios[3].

2.2.2 These two years can be referred to as the 1st modelled year and the 'cap', or the 2nd modelled year. In Figure 1 (below), points Y_1 and Y_2 represent these years. The corresponding benefits for those years, as calculated by the PFM system, are represented on the vertical scale of the chart as B_1 and B_2 respectively.

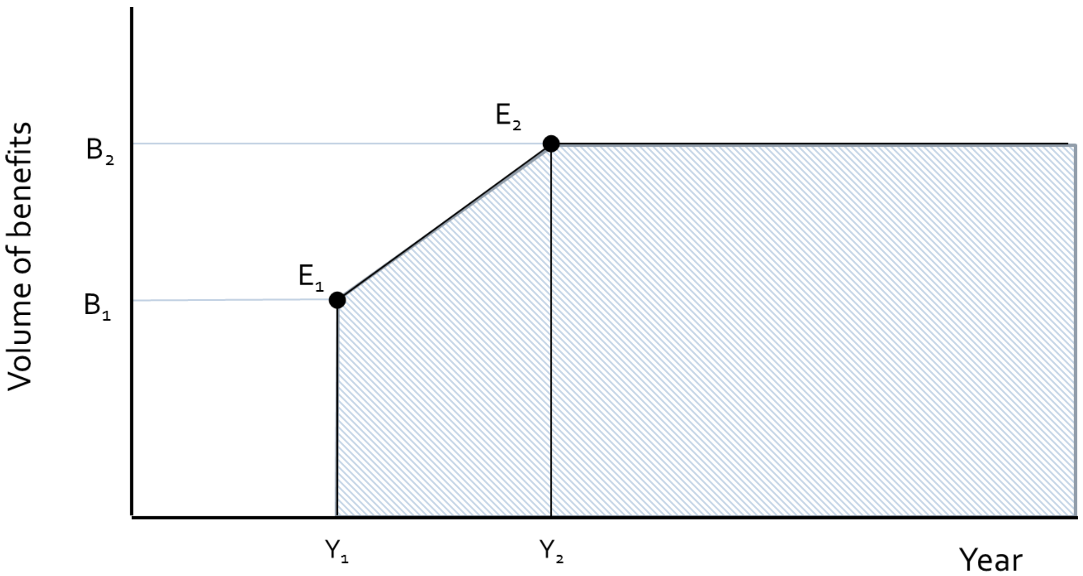

Figure 1: Interpolation and extrapolation of benefits with a demand cap

2.2.3 In line with standard transport appraisal practice, the appraisal module of PFM interpolates benefit and revenue outputs between E_1 and E_2, for the period Y_1 to Y_2, in order to build a profile of benefits through the first part of the appraisal period[4]. For the remaining appraisal period, beyond the 'cap' year, the volumes of benefits (as measured in their natural units) and revenues are held constant at level B_1. The blue shaded area on the chart therefore represents the overall volume of benefits, as expressed in their natural units.

2.2.4 In the appraisal, the values of benefits increase according to their relationship with GDP growth. Forecast benefits and revenues are then discounted back to 2011 prices using the standard discount rates as set out in appraisal guidance[5]. This is all standard practice in transport appraisal.

[3] Details on the methods that are used to calculate benefit and revenue streams may be found in Unit 3.5.3 of the Department for Transport's WebTAG guidance (http://www.dft.gov.uk/webtag/documents/expert/unit3.5.3.php).
[4] Further details can be found in *PLANET framework model (PFM v4.3) – Model description*.
[5] See WebTAG section 3.5.4 and HMT Green Book.(https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent).

2.2.5 Our approach to risk analysis relies on estimating the years in which the different levels of rail demand associated with benefit levels B_1 and B_2 would occur under alternative forecasting scenarios, and reshaping the profile of benefits and revenues accordingly.

2.2.6 This is illustrated Figure 2 which illustrates how the profile of benefits would be re-constructed for a scenario with a lower level of GDP growth.

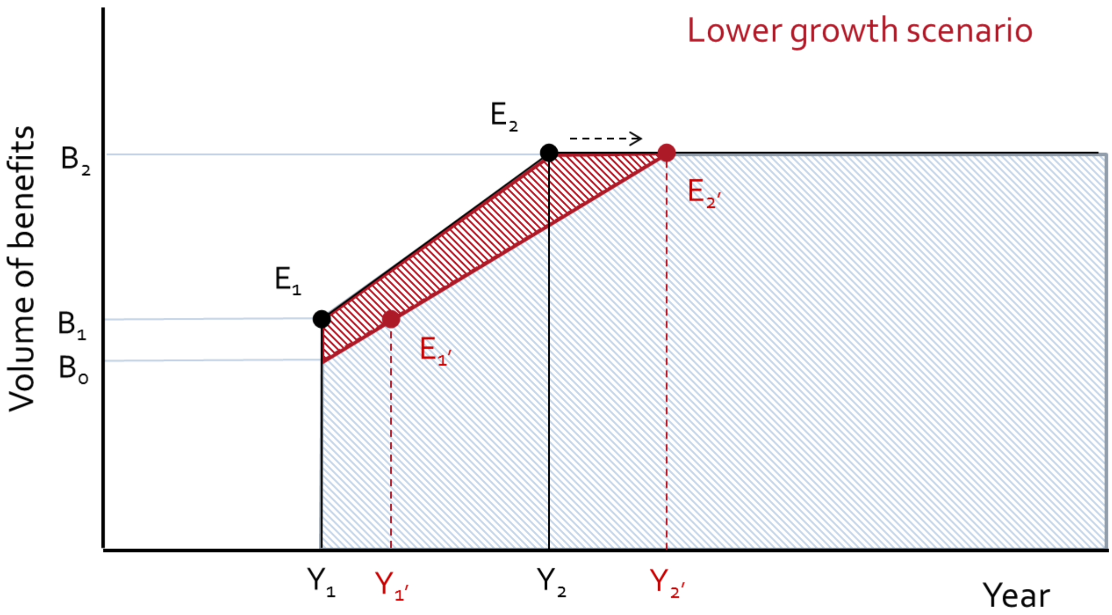

Figure 2: Benefits profile for a low GDP growth scenario

2.2.7 Under an assumption of lower GDP growth, with other factors in the analysis held constant, the levels of demand modelled for first and second modelled years would occur later in time because a lower rate of growth in the economy (lower GDP) would reduce the forecast rate of growth in demand for rail travel. On the diagram, this is represented by shifts along the horizontal axis from Y_1 to $Y_{1'}$ and from Y_2 to $Y_{2'}$.

2.2.8 If we associate the levels of benefits, B1 and B2, from the first and second modelled years with those new years $Y_{1'}$ and $Y_{2'}$ (on the basis that these are the years that the modelled levels of demand would be experienced under the alternative assumptions[6]) this transforms point E_1 and E_2 to $E_{1'}$ and $E_{2'}$ respectively. From these new points, we are able to construct a new profile.

2.2.9 In this instance, given that the benefits for the first modelled year are now associated with a year that is some time after opening, estimation of benefits for the opening year (Y_1) requires some extrapolation from the first modelled year back to the year of opening. On the diagram in Figure 2 the extrapolation gives point B_0 on the vertical axis for year Y_1. Under a higher growth scenario the level of benefits associated with opening year could be interpolated from points $E_{1'}$ and $E_{2'}$.

[6] This implicitly assumes that everything else – with respect to economic growth – remains constant.

2.2.10 In figure 2, the blue area on the chart again represents the new benefit streams. The change (in this case, a reduction) in benefits associated with the lower economic growth is represented by the red shaded area.

2.3 Modelling demand growth

2.3.1 To allow us to rapidly estimate the years in which the different levels of demand are reached under different forecasting assumptions, we have approximated the more detailed Exogenous Demand Growth Estimator (EDGE) model by building a 'meta-model'. EDGE takes population, employment, fares levels and incomes and provides forecasts of exogenous demand to PFM.

2.3.2 The meta-model takes EDGE results and estimates the model's relationships between the outputs and the variables for the risk analysis to make analysis quicker and easier. Specifically it uses the same level of demand used to define the cap year in PFM; this is the long distance rail demand growth.

2.3.3 The model uses the following equation to calculate the overall cumulative demand growth for a given year :

$$Demand = Constant * Yearly\ Growth * Pop^{elasticity} * Fare^{fare\ elasticity} * GDP^{gdp\ elasticity}$$

2.3.4 Given that the elasticity of population across all ticket types and market segments is assumed to be 1, the aggregate population elasticity for all segments taken together is also one, and the elasticity term can therefore be dropped from the relationship. The other terms in the equation, including the yearly growth, and the constant, cover all of the other variables of interest that feed into the exogenous growth calculations.

2.3.5 Terms in the equation have been estimated using regression analysis on outputs from a number of runs from the EDGE forecasting model: two variants on GDP and two variants on fares, all generating 5 yearly interval outputs (30 points in all).

2.3.6 To enable the estimation of the elasticity terms, the constant and the yearly growth term, a manipulation is performed to fix the population elasticity to 1 by dividing by the population throughout. Taking the natural logarithm of both sides of the equation results in a linear equation that is more amenable to analysis. This equation is shown below:

Equation 1 $$\ln\left(\frac{D_t}{P_t}\right) = C + \mathrm{X} \cdot \mathrm{t} + \varepsilon_f \cdot \ln(F_t) + \varepsilon_{GDP} \cdot \ln(GDP_t)$$

- D= Cumulative Demand growth
- P= Cumulative Population growth
- C= Constant Term
- X= other growth per year
- ε_f= Elasticity on fares growth
- F= Cumulative Fares Growth
- ε_{GDP}= Elasticity on GDP per capita growth
- GDP= Cumulative GDP per capita growth

- t= year (base 2010)

2.3.7 This linear equation allows us to use standard statistical regression techniques to estimate the terms.

2.3.8 Taking the exponent of equation 1 results in the following equation, which is used in the risk analysis model:

Equation 2 $$D = e^{C} \cdot (e^{X})^{t} \cdot F^{\varepsilon_f} \cdot GDP^{\varepsilon_{GDP}} \cdot P$$

By replacing e^C by C_0, e^X by G in Equation 2 we see that:

Equation 3 $$D_t = C_0 \cdot G^t \cdot F_t^{\varepsilon_f} \cdot GDP_t^{\varepsilon_{GDP}} \cdot P_t$$

2.3.9 G represents the yearly growth, a constant factor that captures other elements that feed into exogenous demand growth, for example coach fares.

2.3.10 The resultant elasticities, constant term and the growth term are shown in Table 1:

	Fare elasticity, ε_f	GDP elasticity, ε_{GDP}	Constant, C_0	Other Growth/yr, G
Estimate	-0.872	1.227	1.071	1.003

Table 1: Estimated terms from regression analysis of EDGE model sensitivity tests

2.3.11 Table 2 shows diagnostic statistics for the regression. The very high R^2 value (0.997) and the p-value (0.000), resulting from the ANOVA F-test, demonstrate that the overall model is valid for use in the risk analysis.

	R^2	ANOVA	
		d.f	**P- value**
Statistics	0.997	3	0.000

Table 2: Diagnostic statistics from the regression analysis of EDGE model sensitivity tests

2.3.12 Furthermore, a comparison of the meta-model and the EDGE outputs confirms that the meta-model is suitable for the purposes of risk analysis. The table below shows the set of years that the level of demand associated with the cap would occur in, as compared with EDGE modelled outputs, for the standard case and for a number of other sensitivites.

Sensitivity tests	2nd modelled year		
	EDGE	Meta-model	Error
Standard case	2036	2037	+1
RPI+0	2031	2031	0
RPI+2	2050	2049	-1
GDP+25%	2030	2030	0
GDP-25%	2050	2049	-1

Table 3: EDGE sensitivity test

2.3.13 This table shows that there are, in some cases, up to a single year difference in the predictive values when compared to the modelled values. This is primarily the result of rounding, and results in very small differences in the BCR.

2.4 Factoring benefits

2.4.1 In some scenarios, where we have adopted alternative approaches to demand capping, it has been necessary to extrapolate benefits beyond the 2nd modelled year. In doing so, we have deliberately chosen a cautious assumption that benefits will rise only proportionately with increases in demand, i.e. a 10% change in the level of demand leads to only a 10% change in the level of benefits.

2.4.2 Tests using scenarios from PFM confirm this to be a conservative assumption. Figure 3 below shows an analysis of a model run with demand continuing to grow out to 2041. The figure shows that as demand grows, the growth in the level of benefits outstrips that of demand. The ratio of growth between demand and benefits is 1:1.12 for the standard case, and 1:1.16 for the alternative 2041 scenario – both higher than the ratio of 1:1 that is employed in the risk analysis modelling.

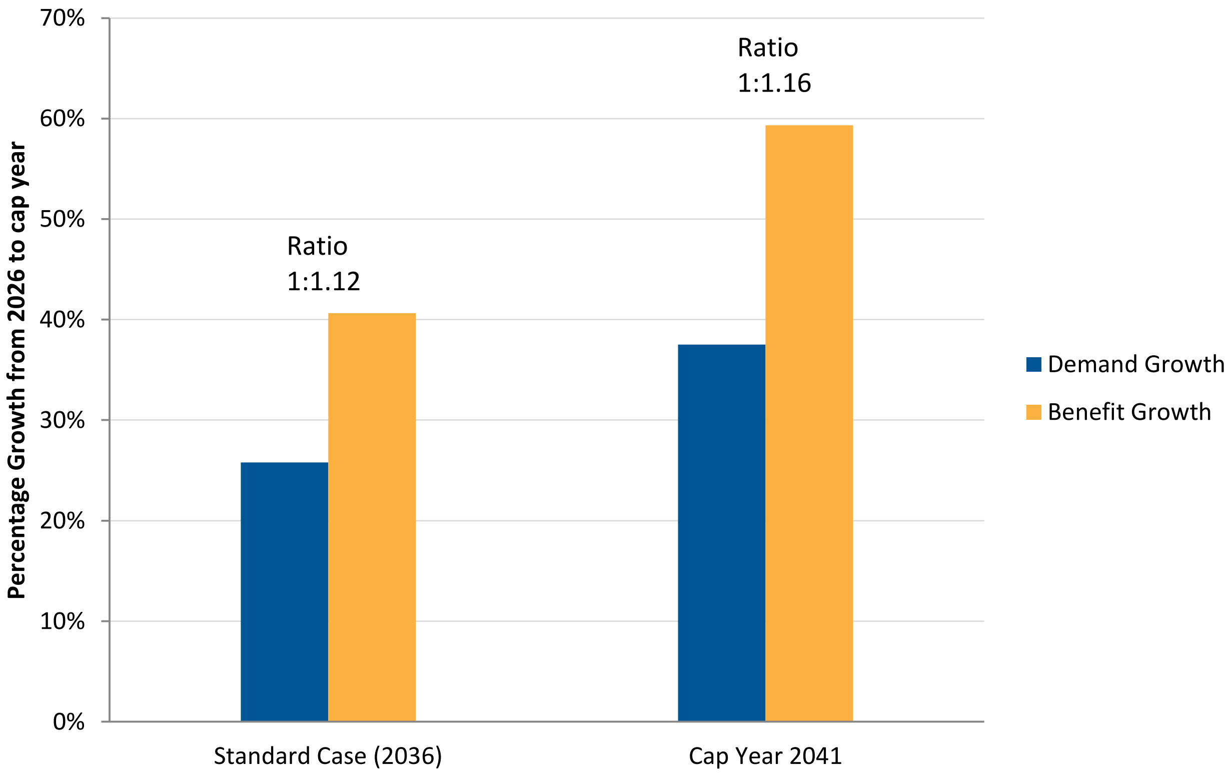

Figure 3: Relationship between demand growth and benefits

2.4.3 All the BCR figures quoted in this document include Wider Economic Impacts (WEIs). The WEIs calculated for the HS2 scheme have three main components: Imperfect competition, agglomeration and labour supply impacts. They are each calculated in different ways, and are therefore given different treatments in the risk analysis.

- Imperfect Competition: Under the standard case imperfect competition impacts are simply calculated as being 10% of the total benefits; therefore, it is a simple matter to calculate the variations to this element of the WEI calculations in the risk analysis.
- Agglomeration: In the standard analysis this is calculated with the Department for Transport's WITA software, which could not be incorporated into the risk analysis framework, and therefore agglomeration benefits are held constant across simulations.
- Labour supply impacts: Similarly, the calculation of labour supply impacts is reliant on the WITA software, and therefore this value is held constant.

2.4.4 In the risk analysis, it is assumed that above inflation fares growth halts in the same year for all simulations as for the standard case model run. This assumption has been sensitivity tested.

3 Inputs/Data assumptions

3.1 Introduction

3.1.1 The factors that have been selected for inclusion as variables in the risk analysis have been chosen on the basis that:

1 They are key drivers of the BCR; and
2 There are reliable sources of information for the parameter and its distribution.

3.1.2 The following variables have been included:

- GDP Growth;
- Non Work Values of Time;
- GDP and Fare Elasticity of Exogenous Rail Demand; and
- Construction cost.

3.1.3 Clearly, these are not the only factors in the calculation of the BCR but they exert a strong influence over the results – particularly GDP growth – and they are the factors that are most amenable to analysis within our framework. The addition of further variables into the analysis could either increase or decrease the variation captured by the distributions, depending on their correlation with the other variables analysed.

3.2 UK GDP growth

3.2.1 In the appraisal of HS2, economic growth determines both how quickly demand grows in the model and how people value travel time-savings from the scheme. It is therefore one of the most critical inputs into the risk analysis.

3.2.2 The GDP projections used in the risk analysis are drawn fromOffice for Budget Responsibility (OBR) forecasts. These forecasts were published in the *Economic and Fiscal Outlook Report* (March 2012) and the *Fiscal Sustainability Report* (July 2012) and match the values used in PFM[7].

3.2.3 The OBR produce two sets of GDP forecasts - short-term forecasts and long-term forecasts. These are handled in the modelling in different ways.

3.2.4 Short term GDP growth forecasts – for the period 2012 to 2016 – are based upon modelling errors in official GDP forecasts since 1987. Figure 4 illustrates the OBR forecasts used in our modelling as a fan chart. As predictions become increasingly uncertain in future years, the uncertainty around the forecasts increases, creating a fan shape.

[7] Further details can be found in *PFM v4.3: Assumptions report* .This document will be published on the HS2 website.

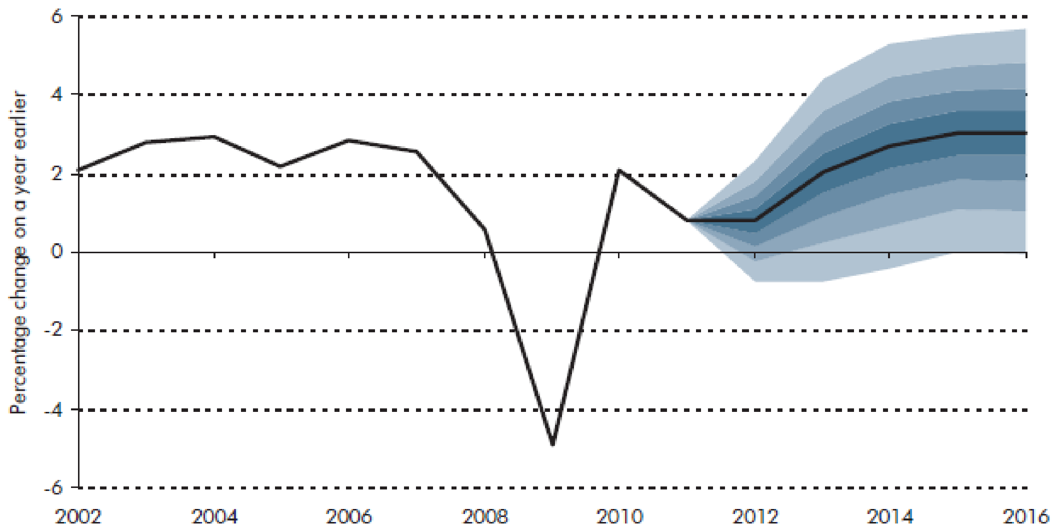

Figure 4: OBR GDP Short term fan chart. Source: Economic and Fiscal Outlook, OBR (March 2012)

3.2.5 The OBR forecasts are based on a two-piece normal (or split normal) distribution. The parameters, as provided by the OBR, are provided in Table 4.

Calendar year	2012	2013	2014	2015	2016
Median	1.0	2.3	2.8	3.1	3.0
Skew (mean - mode)	0.0	-0.5	-0.7	-0.7	-0.6
Standard deviation	1.2	2.0	2.2	2.2	2.2

Table 4: OBR Short term growth statistical parameters

3.2.6 To make the distributions more amenable to analysis within our framework, the distributions have been transformed from calendar years to financial years (starting in April), and from a median with skew and standard deviation, to a mode with an inverse skewness indicator and a standard deviation.

Financial year	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017
Mode, μ	1.0	2.7	3.4	3.7	3.5
Inverse skewness indicator, ϒ	0.0	0.3	0.4	0.4	0.3
Standard deviation, σ	1.2	2.0	2.2	2.2	2.2

Table 5: Transformed short term GDP growth parameters

3.2.7 The OBR long-term GDP growth projection is constructed in a different way. This is built from the sum of two components, productivity growth and employment growth.

3.2.8 In terms of the inputs into the long-term growth forecast, employment growth is simply the combination of population growth and changes in the employment rate. We have no specific evidence to quantify the uncertainty around employment growth; it has therefore not been included in the risk analysis. Population growth (as a component of the Long Term GDP growth projection) is given as a pre-defined series. This approach is consistent with other aspects of the demand modelling where population growth is an input.

3.2.9 The OBR's *Fiscal Sustainability Report* (Jul 2012) provides a central projection and projections for low and high productivity scenarios.

- Central projection: OBR assume in the central projection that whole economy productivity growth will be on average 2.2% a year on an output per worker basis..
- Low/high productivity scenarios: OBR also run alternative scenarios with productivity growth averaging 1.7% and 2.7% respectively. In these scenarios, employment growth remains unchanged whilst productivity is varied.

3.2.10 In incorporating the OBR analysis into the risk analysis model, we have assumed that the variation in productivity growth is normally distributed. The parameters of the distribution are estimated as follows:

- Mean: OBR central GDP growth projection (average productivity growth = 2.2%)
- Standard deviation: by assuming the low-high productivity variant (low: 1.7%; high: 2.7%) are at the 2.5 and 97.5 percentiles of the normal distribution, the standard deviation of the distribution is therefore 0.3%.

3.3 Non business value of time

3.3.1 In the economic case, the two key components of non-business VOT are the base value of time (which provides the value given in WebTAG) and its elasticity to economic growth.

3.3.2 The distributions used in the analysis have been determined according to the method set out in the publication *Advice on Statistical Confidence of Appraisal Non-Work Values* *of Time*[8] with values updated according to the revisions of the October 2013 WebTAG values of time for non-business travellers.

Variable	Commuting/ Other	Point estimate	Standard Error	Implied Distribution
Base VOT (£/hour, 2010 prices, 2010 incomes)	Commuting	6.811	0.476	N(6.812, 0.476)
	Leisure	6.044	0.361	N(6.044, 0.361)
GDP Elasticity	Both	1.000	0.135	N(1.227, 0.025)

Table 6: Probability distribution and parameters for non-business values of time

3.4 Distribution of GDP and fare elasticity of long-distance rail demand

3.4.1 The elasticity model recommended in the Passenger Demand Forecasting Handbook Version 5 (PDFH5) is implemented in PFM using EDGE. However for the sake of the risk analysis we use a meta-model, estimated from EDGE outputs, as explained in section 2.3. The elasticities used in the risk analysis model are effectively a weighted average of the elasiticities in EDGE.

3.4.2 In line with WebTAG guidance, the EDGE elasticities for GDP growth are based on evidence from PDFH5, whereas those for fares are based on PDFH4. The elasticities are subject to variation due to the data sources that generate them and we have used this information on variation to generate distributions for use in the risk analysis.

Fares

3.4.3 In PDFH the fare elasticity of long-distance rail demand is divided into flows in or between three regional categories 'London', 'London and the South east' and 'Rest of Country', and information on variation is therefore available at this disaggregated level. To generate a weighted average variation, the variations for each regional category have been weighted together (according to the proportion of demand they represent[9]) in the following equation:

[8] *Advice on Statistical Confidence of Appraisal Non-Work Values of Time* , Wheat, Wardman and Bates, 2012
[9] As the demand cap relates to trips over 100 miles, trips from London to London, Rest of South East to Rest of South East and London to Rest of South East have been excluded.

$$Var[\varepsilon_O] = Var[w_{LR} \cdot \varepsilon_{LR} + w_{RL} \cdot \varepsilon_{RL} + w_{RR} \cdot \varepsilon_{RR}]$$
$$= {w_{LR}}^2 \cdot Var[\varepsilon_{LR}] + {w_{RL}}^2 \cdot Var[\varepsilon_{RL}] + {w_{RR}}^2 \cdot Var[\varepsilon_{RR}]$$
$$+2 \cdot w_{LR} \cdot w_{RL} \cdot Cov[\varepsilon_{LR}, \varepsilon_{RL}]$$
$$+2 \cdot w_{LR} \cdot w_{RR} \cdot Cov[\varepsilon_{LR}, \varepsilon_{RR}]$$
$$+2 \cdot w_{RL} \cdot w_{RR} \cdot Cov[\varepsilon_{RL}, \varepsilon_{RR}]$$

Flows

LR: London to Rest-of-Country

RL: Rest-of-Country to London

RR: Rest-of-Country to Rest-of-Country

w: Weight, the proportion of flow demand in overall demand

ε: fare elasticity of demand

Var: Variance

Cov: Covariance

(Equation 4: Calculation of the property of variance)

3.4.4 Each of the covariances referenced in equation 1 were calculated/derived from the following equation which expresses the relationship between correlation and covariance:

$$Cov(X, Y) = Var[X] \cdot Var[Y] \cdot Corr[X, Y]$$

Cov: Covariance

Var: Variance

Corr: Correlation

(Equation 5: Relationship between correlation and covariance)

3.4.5 Due to a lack of evidence with respect to the correlation among the individual elasticities a correlation of 1 is assumed, this is a conservative assumption which will lead to a higher overall variance.

GDP

3.4.6 A similar approach was applied for the calculation of a distribution around the GDP elasticity, using flow data as weights from PFM. However, for the GDP elasticity, we have used the elasticities associated with long distance flows.

3.4.7 The resulting standard deviations included within the risk analysis are:

	Standard Deviation
GDP	0.025
Fares	0.039

Table 7: Standard deviation of GDP and fares elasticities

3.5 Construction cost

3.5.1 A full quantified risk analysis has been developed for the Phase One construction costs of the HS2 scheme.

3.5.2 A quantitative cost risk assessment (QCRA) is used to determine the level of contingency that should be added to the base cost estimate. The QCRA includes *threats* that may or may not occur and *tolerance* ranges associated with the status of the price estimation and design development. Both threats and tolerances represent uncertainty to the base cost estimate.

3.5.3 The QCRA uses stochastic risk simulation to allow the cost uncertainties to be represented by ranges rather than single values, and the inclusion of events that may or may not occur. Each input is assigned one or more representative probability distributions which are sampled when the simulation is run.

3.5.4 The simulation produces a range of possible total costs which are usually presented as a cumulative frequency distribution, or s-curve. The s-curve shows the probability that a given cost will not be exceeded. P50 and P95 costs are typical quoted values from the s-curve. P50 is short-hand for *the 50th percentile*. The P50 cost is the cost for which there is a 50% chance of it not being exceeded. The P95 cost has a 95% chance of it not being exceeded.

3.5.5 The P50 value is used in the standard case to generate the point estimate. The full range of the s-curve is used in the risk analysis to generate a distribution for construction costs. For Phase Two, a less well developed QCRA is in place (reflecting the stage of the scheme). Costs used in the standard case for Phase Two therefore include an additional provision of 32%. For the purpose of the risk analysis the P100 and P0 have been assumed to be equal to the minimum and maximum cost taken from the QCRA results.

3.5.6 The distribution of cost contingency used in the risk analysis model is set out in the cumulative frequency graph below.

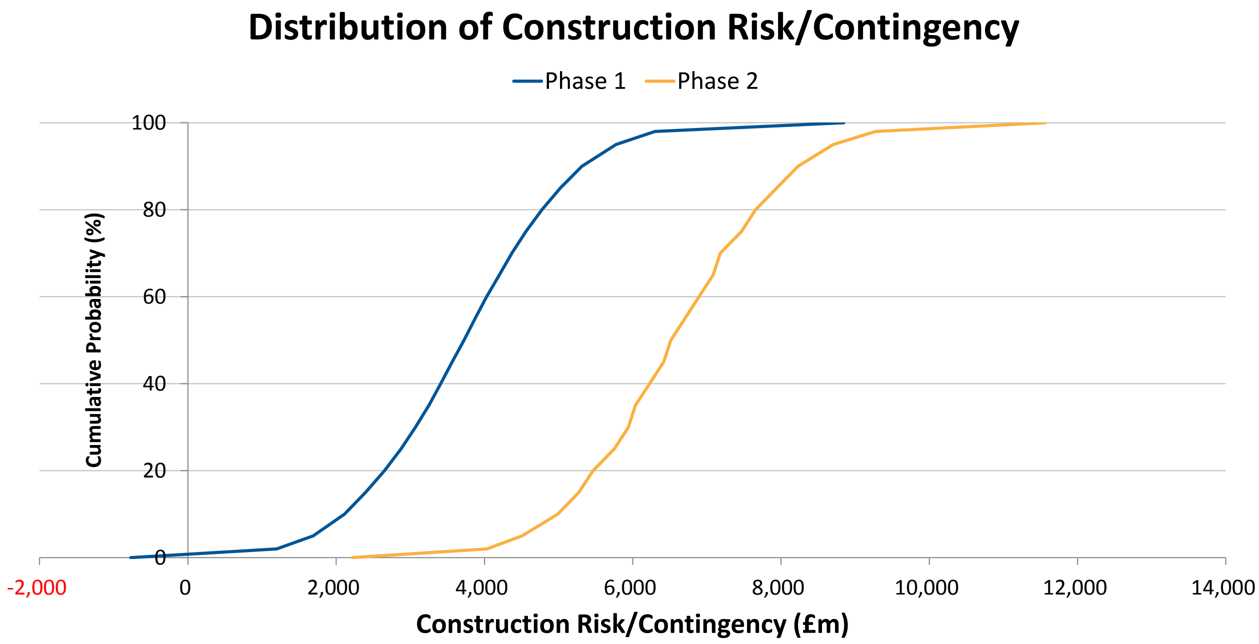

Figure 5: Distribution of construction risk/ contingency

3.5.7 In order to calculate the present value of construction cost, a profile through time of the cost is required. The project spend over time for both phases is illustrated in Figure 6. The risk profile component of project spend is assumed to be the same regardless of the level of risk. In all scenarios, the opening years remain the same.

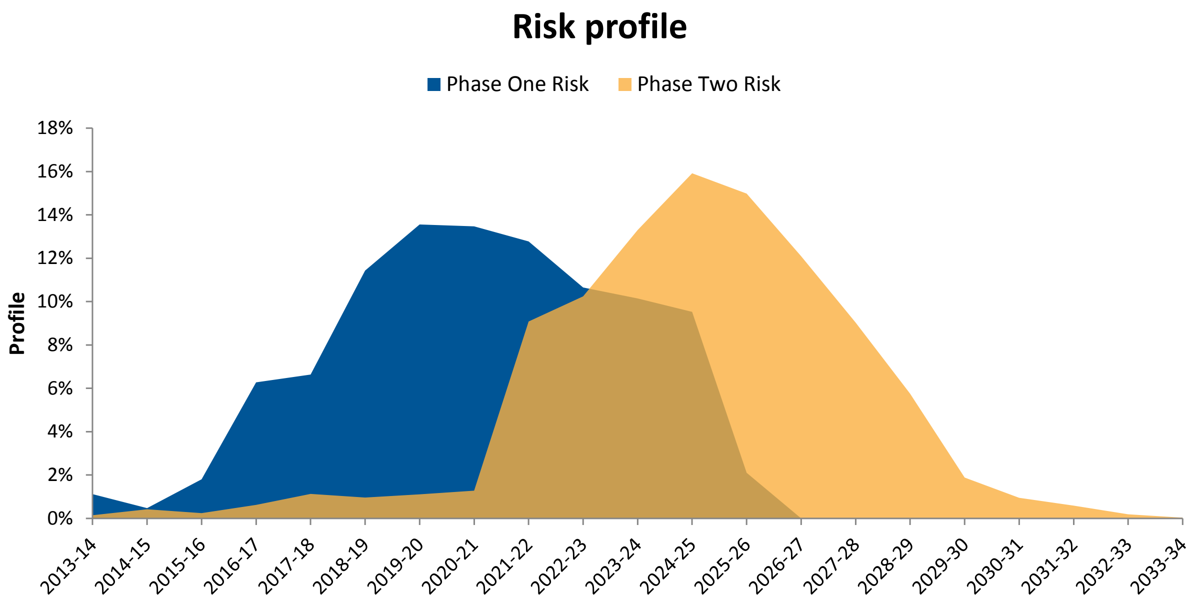

Figure 6: Cost profile for Phase One and Phase Two construction risk

3.6 Alternative values of time

3.6.1 In the *Economic Case for HS2* document we present a scenario based on alternative, higher willingness-to-pay values of time. In part these are based on higher values for business travellers using high-speed rail, drawn from the '*Valuation of Travel Time Savings for Business Travellers*'[10] study by the Institute for Transport Studies (ITS). In addition, we have also adjusted leisure and commuting values of time to reflect the typically longer distance trips affected by the HS2 scheme.

3.6.2 These alternative values for commuting and leisure trips are based on the same evidence as the standard values in the Department for Transport's WebTAG guidance.That evidence provides separate values of time for a range of trip length categories, which correspond to distance band categories used in the National Travel Survey (NTS). In order to create single values for different journey purposes in the appraisal, demand weighted averages are calculated from those values.

3.6.3 However, whereas the standard WebTAG values have been weighted with data from the NTS to be representative of the entire market for motorised travel, for this test we have re-weighted the averages to be more representative of the longer-distance markets served by HS2.

3.6.4 Figure 7 (below) shows the range of values for different lengths of commuting trip.

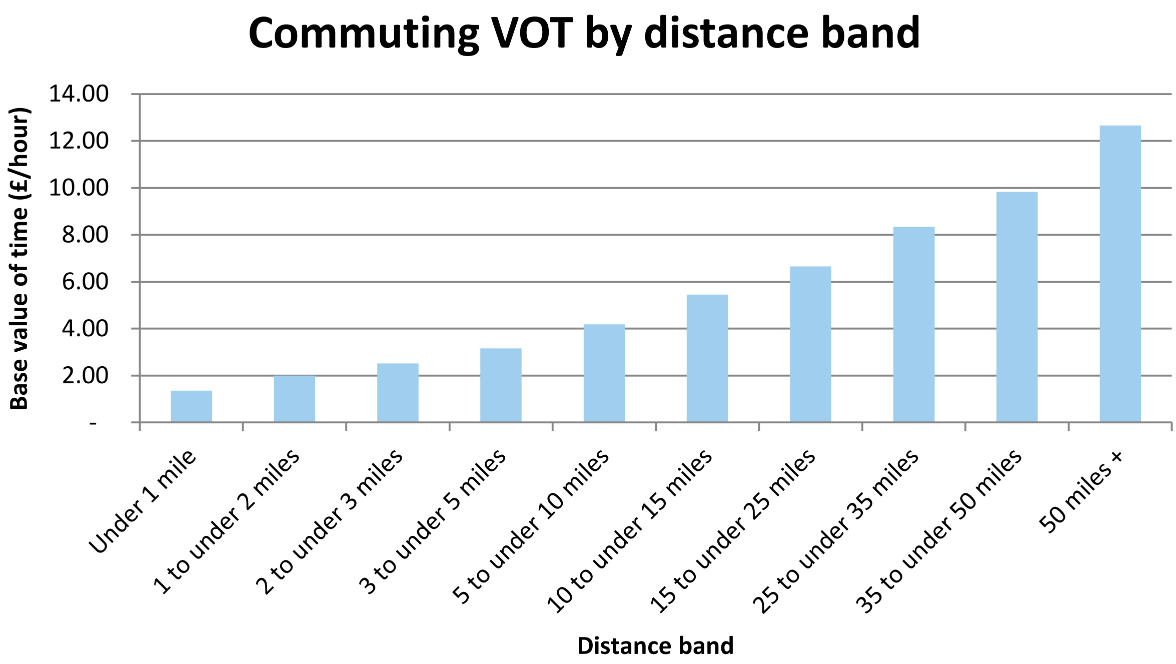

Figure 7: WebTAG source data: Commuting and Leisure Values of Time by distance

3.6.5 Figure 8 illustrates the difference between the trip length profile for all motorised travel – as used in the calculation of the distance weighted average for WebTAG – and

[10] *Valuation of Travel Time Savings for Business Travellers* - (Transport appraisal and strategic modelling website) - www.gov.uk/government/collections/transport-appraisal-and-strategic-modelling-tasm-research-reports

the trip length profile of the benefits delivered by the HS2 scheme. It can be seen that there is a marked difference between the profiles, with the WebTAG values being heavily weighted towards the shorter distance market that will not be served by HS2.

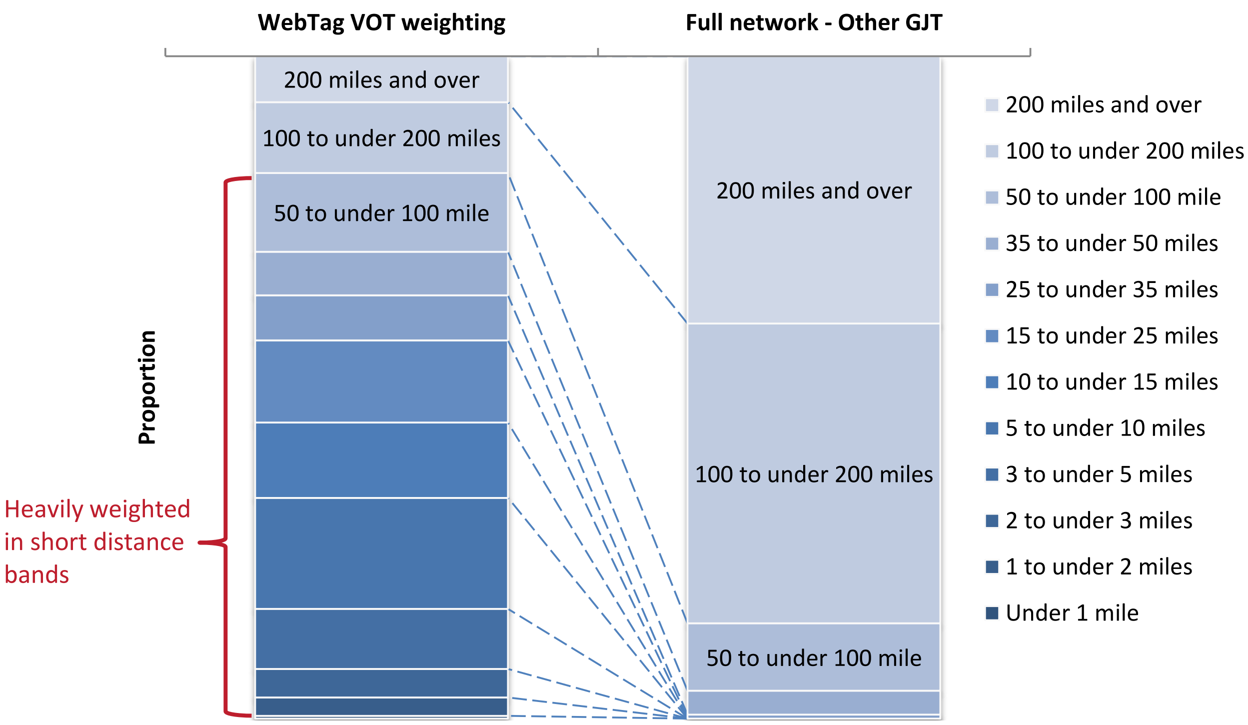

Figure 8: Comparison of trip length profiles used to calculate non-work values of time.

3.6.6 Our alternative values are weighted according to the lengths of the trips for which the benefits are accrued. They are calculated separately for each journey purpose, for Phase 1 and the full network, and for the long-distance and regional components of the Planet Framework Model.

3.6.7 Table 8 (below) shows the resultant values of time that were adopted for the alternative value of time scenario.

Rail - Base VOT (£/hour, 2010 values)		Long distance model	Regional model	Comment
Phase 1	Business	44.66	31.96	**Long distance VOT is base on ITS analysis; regional VOT is the same as WebTAG recommendation.**
	Commuting	12.67	6.91	**The re-weighted VOT is higher than WebTAG recommendation (especially long distance VOT).**
	Other	11.11	5.27	
Full network	Business	44.66	31.96	**Similar to above**
	Commuting	12.31	6.91	
	Other	10.72	5.28	

Table 8: The values of time used for the alternative value of time scenario

3.7 Demand growth assumptions – aviation approach

3.7.1 In the analysis conducted to produce the Department for Transport's UK Aviation Forecasts[11], forecasts of air passenger demand are produced using an approach that is based on a concept of 'market maturity'. In the *Economic Case for HS2*, we have tested a similar approach as an alternative to the standard 'demand cap'. Unlike under the standard 'demand cap' approach, the rate of demand growth declines gradually according to the stage of market maturity rather than stopping abruptly once the level of the demand cap has been reached.

3.7.2 Under this alternative approach, the GDP elasticity of demand (ε_{GDP}) is an indicator of the maturity of the aviation market. With a lower GDP elasticity of demand, the market is more mature and hence less responsive to growth or decline in GDP level.

3.7.3 Table 9 (below) defined five stages of market maturity according to the GDP elasticity fo demand.

Maturity/ saturation stage	GDP elasticity value
Stage 1 (Full immaturity)	Constant and substantially greater than 1
Stage 2	Decreasing but still greater than 1
Stage 3	Approaching 1
Stage 4 (Full maturity)	1
Stage 5 (Full saturation)	0

Table 9: Aviation market maturity elasticities

3.7.4 The National Air Passenger Demand Model (NAPDM) that is used to produce the forecasts treats different markets as being at different stages of maturity. According to their stage of maturity, the markets start to mature in different years as shown in Table 10.

[11] UK aviation forecasts 2013: https://www.gov.uk/government/publications/uk-aviation-forecasts-2013

Maturity of markets	**Maturity starts**
Most mature	2010
Fairly mature	2015
Least mature	2025

Table 10: Start year for different level of market maturity under the aviation approach

3.7.5 In addition, different demand growth assumptions are used to determine how quickly the elasticities decline and at what point in the future the decline would end. For instance, under low growth assumptions, the GDP elasticity of demand would decline to zero in seventy years.

3.7.6 When implementing these assumptions in the risk analysis scenario, we have adopted the most conservative assumptions, which lead to the lowest forecasts of growth over time:

- The UK long distance rail market is in the 'most mature' category, and therefore, rail market maturity has been underway since 2010; and
- The lowest demand growth assumption is applied i.e. the GDP elasticity of demand declines linearly to zero (full saturation) over 70 years.

3.7.7 In the standard case risk analysis, long distance rail demand forecasts are based on the meta-model, given as:

$$D_t = C_0 \cdot G^t \cdot F_t^{\varepsilon_f} \cdot GDP_t^{\varepsilon_{GDP}} \cdot P_t$$

- D= Cumulative Demand growth (base 2010)
- P= Cumulative Population growth
- C_0= Constant Term
- G= yearly growth
- ε_f= Elasticity on fares growth
- F= Cumulative Fares Growth
- ε_{GDP}= Elasticity on GDP growth
- GDP= Cumulative GDP per capita growth
- t= year (base 2010)

The meta-model uses the following parameters

Parameters	Fare elasticity, ε_f	GDP elasticity, ε_{GDP}	Constant, C_o	Other Growth/yr, G
Values	-0.872	1.227	1.071	1.003

Table 11: Parameters used for the aviation approach meta-model

3.7.8 In order to implement NAPDM's maturity assumptions, a declining series of GDP elasticities of demand are applied in the meta-model. Table 12 below, shows how the elasticities reduce on a year-by-year basis.

Year	2010	2011	...	2080 and later
ε_{GDP}	1.227	1.209	...	0

Table 12: Year on year reduction in GDP elasticities under the aviation approach

3.7.9 These are applied as follows in the meta-model for the alternative scenario:

At 2011,

$$D_t = C_0 \cdot G \cdot {F'}_t^{\varepsilon_f} \cdot {GDP'}_t^{\varepsilon_{GDP}} \cdot {P'}_t$$

From 2011 onwards,

$$D_{t+1} = D_t \cdot G \cdot F_t^{\varepsilon_f} \cdot GDP_t^{\varepsilon_{GDP}} \cdot P_t$$

- D'= Cumulative Demand growth (base 2010)
- P'= Population growth
- C_0= Constant Term
- G= yearly growth
- ε_f= Elasticity on fares growth
- F'= Fares Growth
- ε_{GDP}= Elasticity on GDP growth
- GDP'= GDP per capita growth
- t= year (base 2010)

3.7.10 Two further assumptions are made in the scenario:

- above inflation fares growth halts in 2036;
- after 2080, when the market is fully saturated, population growth is the only driver of demand.

3.7.11 Figure 9 shows the growth of demand under these assumptions.

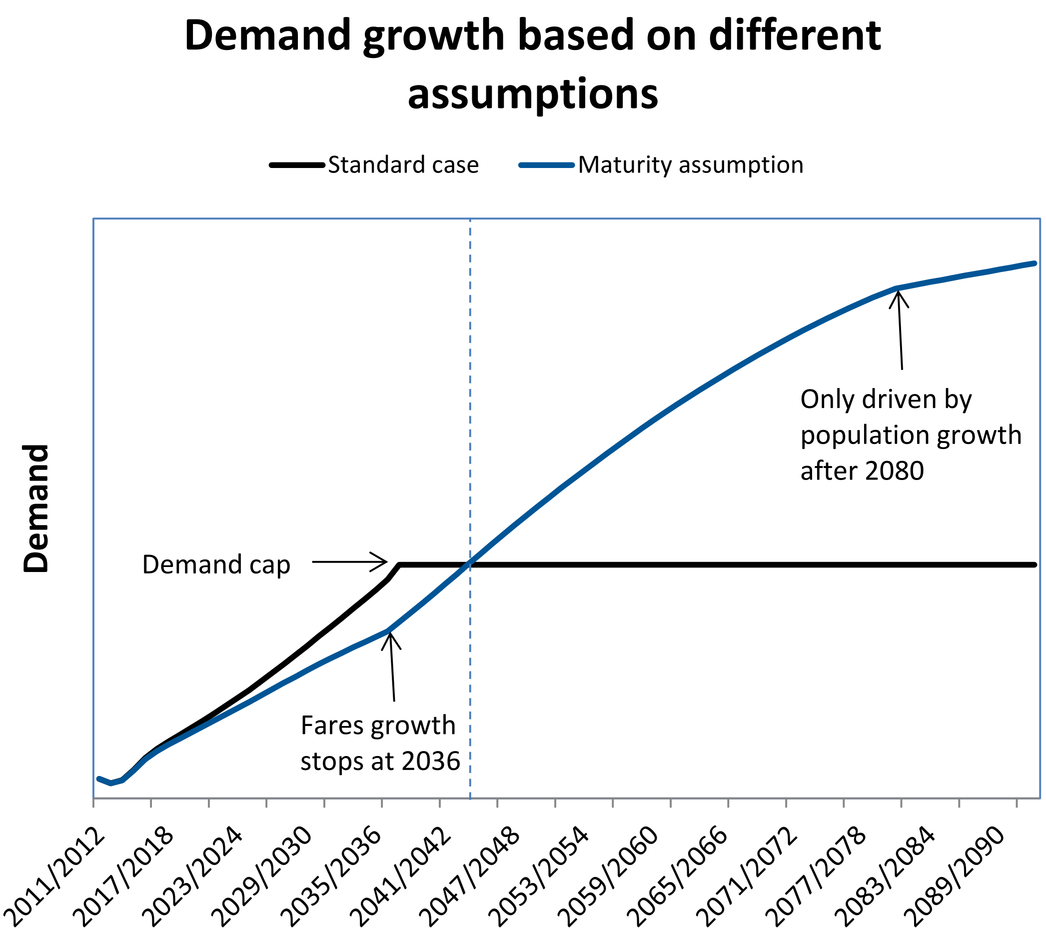

Figure 9: Demand profile under the gradual market maturity assumptions

4 Glossary

Definitions	Acronym	
Analysis of Variance	ANOVA	A method of partitioning the total variation present in a data set into components each component being attributed to a identified source of variation
Appraisal Period	-	The assumed useful life of the assets for analysis
Benefit Cost Ratio	BCR	The ratios of project benefits to project costs
Degree of Freedom	d.f	Any of the statistically independent values of a sample that are used to determine a property of the sample, as the mean or variance
Demand Cap Level	-	The maximum number of passengers that HS2 is modelled to carry
Demand Cap Year	-	The year in which the demand cap is reached
Department for Transport	DfT	The government department responsible for the English (and some of the Scottish) transport network
Exogenous Demand Growth Estimator	EDGE	The demand forecasting tool that feeds into the PLANET Framework Model
Elasticity	-	The responsiveness of a change in X as a result of a change in Y
Full Network	-	The extent of the HS2 network currently being planned for construction
Gross Domestic Product	GDP	The market value of all officially recognised final goods and services produced in the UK within a given period
High Speed Rail	HSR	A railway that can operate at speeds of over 150 mph
Latin Hypercube		The Latin Hypercube method is a stratified sampling method that allows the accurate generation of a realistic probability distribution
Meta - Model	-	A meta-model is a model of a model Within the Risk Analysis the meta-model is a tool which estimates the level of demand growth in a given year
National Air Passenger Demand Model	NAPDM	Department for Transport Model which forecast national air passenger demand
National Travel Survey	NTS	The primary source of data on passenger travel patterns in Great Britain
Office for Budget Responsibility	OBR	An independent body that analyses the UK's public finances
Office for National Statistics	ONS	The UK's largest independent producer of official statistics
P Value	-	In statistical significance testing the p-value is the probability of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true
Planet Framework Model	PFM	The computer model used by HS2 to analyse the future demand for rail travel in the UK
Passenger Demand Forecasting Handbook	PDFH	A summary of over 20 years of research on rail demand forecasting, service quality and fares
Phase One	-	The section of HS2 between London and the West Midlands with a connection via the West Coast Main Line at conventional speeds to the North West and Scotland and to the Channel Tunnel via HS1. Phase One

Definitions	Acronym	
		includes stations at London Euston, Old Oak Common (West London), Birmingham Interchange (near the National Exhibition Centre and Birmingham Airport) and Curzon Street
Phase Two	-	The section of HS2 that extends beyond the West Midlands to Manchester and Leeds with connections to conventional railway lines via the West Coast and East Coast Main Lines. Phase Two includes stations at Manchester Airport, Manchester Piccadilly, East Midlands Hub (between Nottingham and Derby), Sheffield Meadowhall and Leeds
Quality Assurance	QA	The processes, governance and procedures that ensure the quality and accuracy of analytical results
Quantified Risk Assessment	QRA	A formal method of calculating the quantity of individual risks
Released Capacity	-	The availability on the existing network created by the introduction of HS2
Retail Price Index	RPI	An alternative measure of inflation that was previously adopted by the government as the official measure of price increases
Standard Case	-	Our scenario which most rigidly applies the assumptions in the DfT's WebTAG guidance
Values Of Time	VOT	Implicit value people place on time
Web Based Transport Analysis Guidance	WebTAG	The Department for Transport's website that provides guidance on how to conduct transport studies
Wider Economic Impacts	WEIs	The agglomeration, imperfect competition and increased labour force participation benefits