HS2 Phase Two

Risk analysis for the Economic Case
Technical documentation

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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) histograms in the report *HS2 Phase Two: Crewe to Manchester, West Midlands to Leeds Economic Case*.

1.1.2 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.

1.1.3 In the many business cases, one scenario is presented as a 'central case' and the calculated BCR is presented as a certainty, with little understanding of its robustness. 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 the HS2 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 A similar document was published as part of the HS2 economic case in 2013[1]. Since then there have been numerous updates to the methodology and this document aims to explain the current approach which is used in the production of the Economic Case.

1.2 Document structure

1.2.1 There are three further chapters in this report. Chapter 2 outlines the aims of the risk analysis, Chapter 3 details the methodology, and Chapter 4 provides detail on the inputs and assumptions.

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

[1] Risk analysis for the HS2 economic case: Technical documentation https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/365339/S_A_2_Risk_analysis_for_the_HS2_Economic_Case_-_Technical_documentation.pdf

2 Our approach to analysing risk

2.1 Introduction

2.1.1 The HS2 Risk Analysis is a Monte Carlo model, which estimates the combined impact of multiple sources of quantifiable risk on an outcome. The approach relies on the definition of ranges of risk around key variables, 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 scheme. The BCR is calculated by dividing the net transport benefits by the net cost to Government. For each simulation every variable within the risk analysis is randomly generated using its defined distribution. The simulated value is then entered into the BCR calculation. Afterwards all the models are recalculated and combined to produce a BCR for the simulation. Once all of simulations have been calculated, they are used to produce key statistics (mean, median etc.) and histograms for the Economic Case.

2.1.3 A large 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 running quickly and automatically.

2.1.4 To reduce the time taken to accurately estimate the range of BCR values, the input variables are generated using the Latin-Hypercube sampling (LHS)[2]. "*The distinguishing feature of Latin Hypercube sampling is stratification of the input probability distributions. A sample is then chosen from each stratified layer of the input distribution. Sampling is forced to represent values in each layer and thus recreates the input distribution. Convergence tests show that this method of sampling converges faster on the true distributions compared with Monte Carlo sampling.*"

2.1.5 As in previous business cases, each risk analysis run uses 2,000 simulations to assess the variability of the BCR. Previous work in 2013 suggested that increasing the number of simulations to 3,000 or 5,000 did not improve the analysis, but did incur a significantly greater runtime.

3 Model Methodology

3.1 Outline

3.1.1 Many of the variables used in the risk analysis do not impact directly on any of the models outlined above. This is because the economic appraisal spreadsheet analyses the outputs from the Planet Framework Model (PFM), which in turn uses values from Exogenous Demand Growth Estimator (EDGE) model and it is this model which uses data on GDP, fares etc.

[2]Public sector business cases using the five case model: updated guidance (2015) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/469317/green_book_guidance_public_sector_business_cases_2015_update.pdf

Further details on the modelling process can be found in Assumptions Report: PLANET Model Version 6.1c and PLANET Framework Model (PFM6.1c) Model Description.

3.1.2 The runtime for both of these models is very large and as such neither can be used as part of the risk analysis. To allow for the rapid estimation of model results two regression-based simple models have been constructed. The first acts as a meta-model for EDGE, estimating how long distance demand would change under various economic assumptions. The second estimates how levels of benefits and revenues changes as the level of demand changes. The process for doing this is outlined in the following sections.

3.2 Modelling demand growth

3.2.1 EDGE takes population, employment, fares levels, incomes and other data to provide forecasts of exogenous demand to PFM. The data comes from a wide variety of sources and is a mixture of regional and national data depending on the forecast year.

3.2.2 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. To simplify the model it only works at a national level and it ignores many of the smaller factors that affect demand such as other public transport fares.

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

$$D = C * AG^{t} * Pop^{p\ elast} * Fare^{f\ elast} * GDP^{GDP\ elast}$$

3.2.4 Where; D = Demand, C = a constant and AG = annual growth.

3.2.5 To simplify this equation we take the logarithm of both sides and then rearrange, taking advantage of the properties of the logarithm function:

$$\ln(D) = \ln(C * AG^{t} * Pop^{p\ elast} * Fare^{f\ elast} * GDP^{GDP\ elast})$$

$$\ln(D) = \ln(C) + \ln(AG^{t}) + \ln\left(Pop^{p\ elast}\right) + \ln\left(Fare^{f\ elast}\right) + \ln(GDP^{GDP\ elast})$$

$$\ln(D) = \ln(C) + t\ln(AG) + \text{p elast} * \ln(Pop) + Fare\ elast * \ln(Fare) + \text{GDP elast} * \ln(GDP)$$

3.2.6 The final equation is now in a linear form. To make this clearer the notation X' is used to represent ln(x)

$$\mathrm{D}' = \mathrm{C}' + \mathrm{AG}'t + (\text{p elast} * \mathrm{Pop}') + (f\ elast * Fare') + (GDP\ elast * GDP')$$

3.2.7 The terms in the equation are then estimated using regression analysis on outputs from a number of runs from the EDGE forecasting model: two variants on GDP, two variants on fares and two variants on population. Each sensitivity test produces a series of values from 2014 to 2036 (23 points).

3.2.8 To enable the estimation of the elasticity terms using a simple linear regression we take the natural logarithm of both sides of the equation resulting in a linear equation that is more amenable to analysis.

3.2.9 During the process of estimating the regression it became apparent that the demand response varied before and after 2026. This made it difficult to fit a regression curve as long distance demand appeared to grow faster after 2036. This is likely to be due to the underlying source data used for EDGE which is more disaggregated in the short term but aligns with the national forecasts in later years. To correct for this the dataset was separated with two regressions run, one for before 2026 and another for later years.

3.2.10 The estimated elasticities, the constant term and the growth term are shown in Table 1 below.

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

	GDP Elasticity	Fare Elasticity	Pop Elasticity	Constant	Annual Growth
Before 2026/27	1.20	-0.88	1.04	0.99	1.00
After 2026/27	1.22	-1.03	1.01	0.92	1.01

3.2.11 Furthermore, a comparison of the meta-model and the EDGE outputs confirms that the meta-model is suitable for the purposes of risk analysis. For all of the sensitivity tests the model has an accuracy of within 1.1% of the true value (Table 2).

Table 2: EDGE sensitivity test results

Sensitivity tests	**Long Distance Trips Index 2036 (2014/15 = 1)**		
	EDGE	**Meta-Model**	**Error %**
Standard case	1.77	1.77	0.0%
RPI+0	2.06	2.08	1.1%
RPI+2	1.50	1.50	0.2%
GDP Growth -25%	1.52	1.52	0.0%
GDP Growth +25%	2.05	2.05	-0.4%
ONS Low Population	1.66	1.66	0.0%
ONS High Population	1.86	1.87	0.4%

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

3.3.1 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 the investment (in this case HS2). 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. To calculate a profile of benefits and revenues over time this process is repeated for at least two forecast years.

3.3.2 HS2 uses two modelled years. The first modelled year is 2026, the year of opening. In line with other rail schemes the second modelled year is 20 years after the year of appraisal. For the Phase 2b Economic Case this is 2036.

3.3.3 For the remaining appraisal period, beyond the second modelled year, the volumes of benefits and revenues are held constant. This is in line with standard rail appraisal.

3.3.4 Due to this methodology the entire stream of benefits and revenues over the full appraisal period can be estimated by adjusting only the values for the two modelled year.

3.3.5 Therefore a simple linear regression was performed to identify the relationship between long distance demand and a measure of benefits, the extrapolation index (EI). The EI is calculated by subtracting the 2026 level of benefits and dividing by the difference between the 2026 and 2036 benefits. In the reference case the 2026 EI is 0 and the 2036 EI is 1.

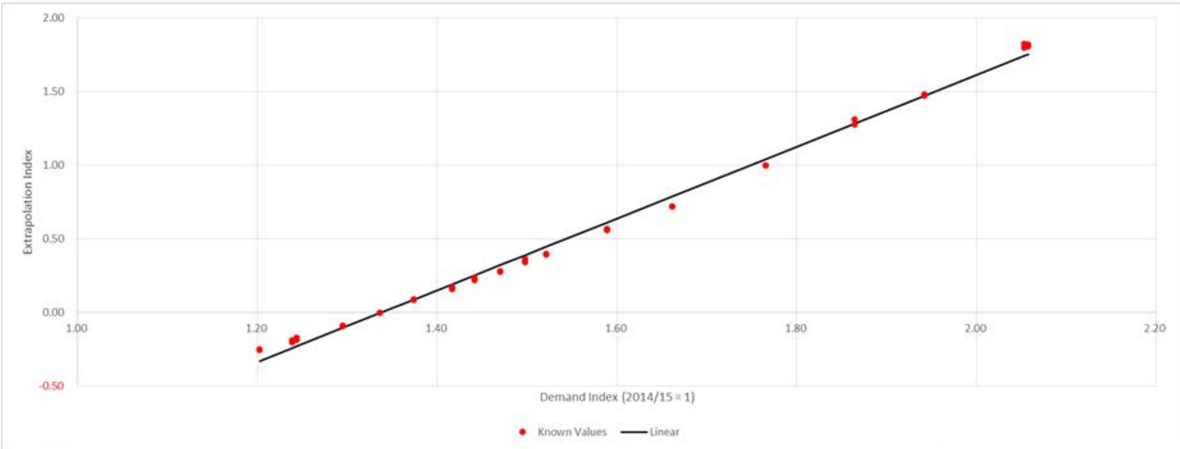

Figure 1: Graphing the relationship between the extrapolation index and the demand index

3.3.6 This regression then allows for an equation to be formed, EI = (2.43*DI) - 3.25, that defines the relationship between demand and the required adjustment to benefits. The risk analysis model then takes the forecasted demand from the EDGE meta-model and calculates a new EI which is entered in the economic appraisal to compute the level of benefits and revenues for each simulation.

3.3.7 The methodology outlined above has changed substantially from the previous version of the economic case. In PFM v5, demand was allowed to increase to a certain level (the demand cap) and the year in which this occurred was considered the second modelled year.

3.3.8 Figure 2 illustrates how the profile of demand would be adjusted for a scenario with a lower level of GDP growth. For simplicity it is assumed that the demand cap also gives a second modelled year of 2036.

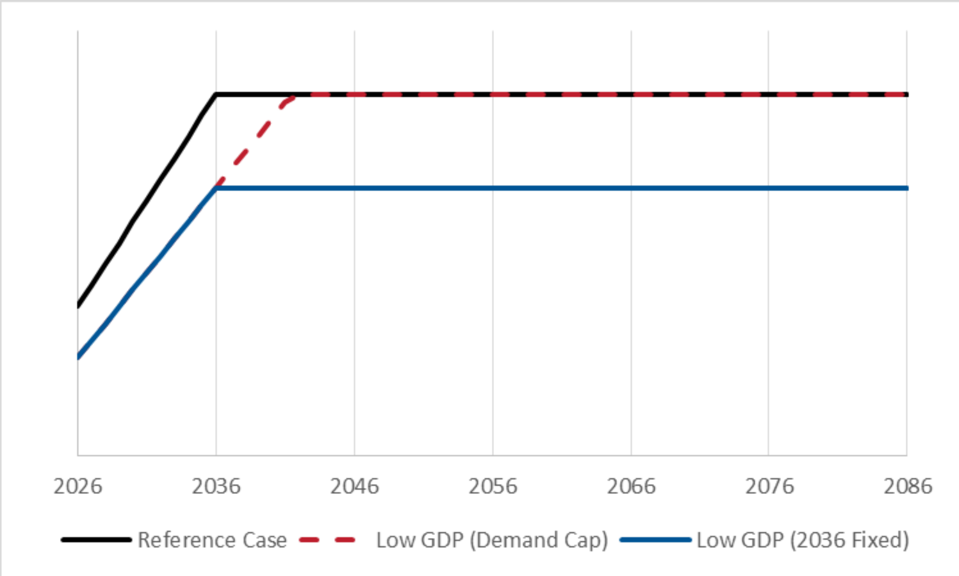

Figure 2: Demand growth changes due to new demand cap methodology

3.3.9 During a simulation where the GDP growth rate is forecast to be lower, the level of demand modelled would also be lower due to the positive relationship between GDP growth and demand growth. However in the old methodology the demand cap allows for growth to continue and reach the demand cap later. This creates a gap between the simulation and the reference case but only in the short term (the gap between the black and red lines). In the long term both simulations have demand reaching the cap level and so the level of benefits is the same for roughly 40 years of the appraisal. Under the new method demand stops growing in 2036 regardless and this leads to a permanently lower level of demand (the gap between the blue and black lines).Therefore, under this new method, changes in assumptions affecting demand levels will have a greater impact on results than seen in previous Economic Cases.

3.4 Estimating Wider Economic Impacts

3.4.1 All BCR figures quoted in the economic case include Wider Economic Impacts (WEIs). The WEIs calculated for the HS2 scheme have three main components: output change in imperfectly competitive markets, agglomeration and labour supply impacts. A full description of the method for calculating WEIs and what effects they measure can be found in Tag Unit A2.1[3] Due to methodological differences they are calculated using different methods which are outlined below.

3.4.2 **Output Change in Imperfectly Competitive Markets:** Under the standard case imperfect competition impacts are simply calculated as being 10% of the total business benefits; therefore, it is a simple matter to calculate the variations to this element of the WEI calculations in the risk analysis.

3.4.3 **Agglomeration and Labour Supply Impacts:** In the standard analysis this is calculated with the Department for Transport's Wider Impacts in Transport Appraisal (WITA) software. A

[3] WebTAG Unit A2.1
http://www.gov.uk/government/uploads/system/uploads/attachment_data/file/427091/webtag-tag-unit-a2-1-wider-impacts.pdf

small number of sensitivity tests have been run to attempt to estimate the relationship between long distance demand and the resulting WEIs. This process is relatively simple and less well developed than other elements of the risk analysis. This could be improved in future versions of the economic case.

4 Inputs/Data assumptions

4.1 Outline

4.1.1 Data has been collected from a variety of sources to inform the input distributions for the Risk Analysis model. In the vast majority of cases the mean of the distribution is set to equal the value used in the main appraisal process and the only additional data has been the estimate of the standard deviation.

4.1.2 The variables selected for inclusion in the risk analysis have been chosen on the basis that they are key drivers of the BCR and that there are reliable sources of information for the parameter and its distribution. The full list of variables is outlined in Table 3.

Table 3: Variables selected for inclusion in the risk analysis modelling

Variable	Model(s) Influenced	Included in Risk Analysis	Varied in Scenarios
Short Term GDP Growth	Demand & Economic Appraisal	Yes	Yes
Long Term GDP Growth	Demand & Economic Appraisal	Yes	Yes
Fare Growth	Demand & Economic Appraisal	No	Yes
Value of Time	Economic Appraisal	Yes	No
VOT Elasticity	Economic Appraisal	Yes	No
GDP Elasticity	Demand	Yes	No
Fare Elasticity	Demand	Yes	No
P1 Construction Risk	Capital Cost	Yes	No
P2A Construction Risk	Capital Cost	No	Yes
P2B Construction Risk	Capital Cost	No	Yes
P1 Rolling Stock Risk	Capital Cost	Yes	No
P2B Rolling Stock Risk	Capital Cost	Yes	No

4.1.3 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 model. 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.

4.2 UK GDP growth

4.2.1 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 the most critical input for the risk analysis.

4.2.2 The GDP projections used in the risk analysis are drawn from Office for Budget Responsibility (OBR) forecasts. These forecasts were published in the *Fiscal Sustainability Report* (July 2015) and the *Economic and Fiscal Outlook Report* (December 2015) and match the values used in PFM[4].

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

4.2.4 The OBR short term forecasts are based on a split-normal distribution. The parameters, as provided by the OBR, are provided in Table 4.

Table 4: OBR Short term growth statistical parameters

Calendar year	2015	2016	2017	2018	2019	2020
Median	2.40	2.40	2.50	2.40	2.30	2.30
Skew	0.00	-0.10	-0.40	-0.60	-0.60	-0.60
Standard Deviation	0.70	1.20	1.80	2.10	2.30	2.40

4.2.5 These can be used to produce a fan chart of possible values for annual GDP growth. The fan chart published by the OBR as part of their November 2015 forecast is shown in Figure 3.

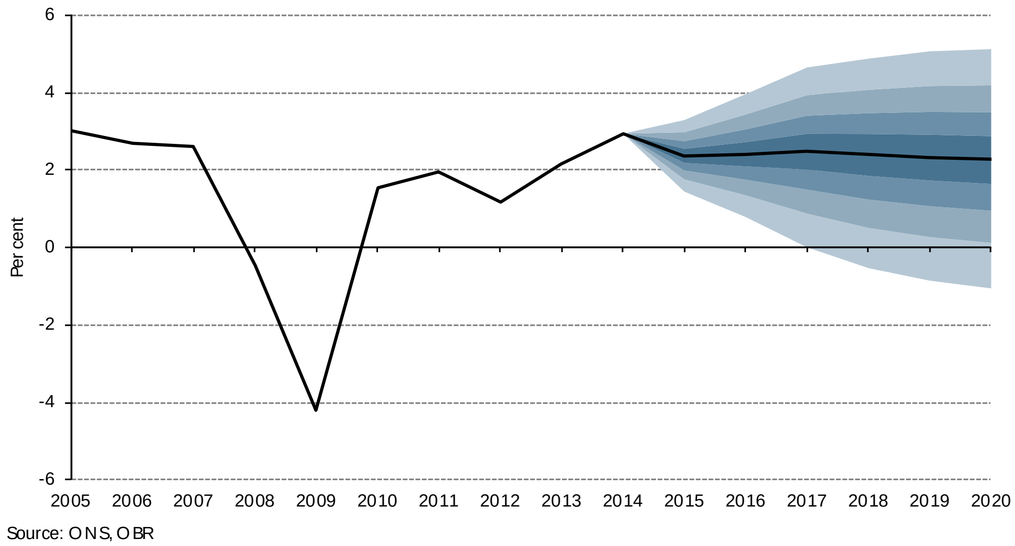

Figure 3: OBR GDP Growth Forecast (Nov 2015)

4.2.6 As the graph clearly shows, the level of uncertainty around the GDP forecast increases with each year. It is worth noting that in line with the OBR assumptions each year's forecast is independent of each other year. This is likely to be unrealistic but there is a lack of data on the correlation between GDP forecasts in different years.

[4] Further details can be found in *PFM v6.1c: Assumptions report*.

4.2.7 The OBR long-term GDP growth projection is constructed in a different way. Long term growth is assumed to be normally distributed with the mean value matching the OBR central GDP growth projection.

4.2.8 To estimate the standard deviation (SD) of long term GDP growth the 2013 economic case used two OBR sensitivities which assumed different levels of productivity. Since then the OBR has not updated these sensitivities and as such the standard deviation has not been updated since 2012.Therefore we retain the previous standard deviation of 0.26% which is derived from the OBR's *Fiscal Sustainability Report* (July 2012).

4.3 Value of Time

4.3.1 The value of time (VOT) research work[5] provided confidence intervals for the mean value of time. This allows for an estimate of the SD to be calculated by assuming that the value of time is normally distributed about the mean. In the case of business value of time the guidance has suggested a distance weighted approach where the value of time is different depending on the distance travelled. It has not been possible to create a formula to adjust the SD for different distances.

4.3.2 As such the SD is used to model an adjustment factor, with mean 0, and the entire VOT curve is moved up or down depending on the value of this adjustment factor in each simulation.

4.3.3 As the distance-based approach as formally been accepted into guidance there is now more certainty over which VOT to use. Therefore sensitivity tests where the Leisure and Commuting VOT are also distance weighted have not been repeated.

4.4 Non-business Value of Time elasticity

4.4.1 The standard deviation used in the analysis has not been updated since the 2013 economic case. Therefore the non-business VOT elasticity remains modelled by a Normal distribution with mean 1 and SD 0.135.

4.5 Fares & GDP Elasticities

4.5.1 In line with WebTAG guidance, the EDGE elasticities for GDP growth are based on evidence from PDFH5.1, whereas those for fares are based on PDFH4.

4.5.2 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. Similarly the GDP elasticity is divided in 'from London' and 'to London' flow. To generate an overall variation, the variations for each regional category have been averaged together using weightings from the central case EDGE model run.

4.5.3 The resulting standard deviations included within the risk analysis are shown in Table 5.

[5] Available at https://www.gov.uk/government/publications/values-of-travel-time-savings-and-reliability-final-reports

Table 5: Standard deviation of GDP and fares elasticities

	Standard Deviation
GDP Elasticity	0.025
Fares Elasticity	0.042

4.6 Capital Cost Risk

4.6.1 For Phase One, 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.

4.6.2 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.

4.6.3 Due to the earlier stage of design of Phase Two, the Phase 2a and Phase 2b cost risk is estimated using optimism bias (at 40%) rather than a QCRA. A sensitivity test with optimism bias set at 50% has been included in the economic case to compensate for the lack of QCRA.

4.6.4 A quantified risk analysis has also been developed for the rolling stock costs of both Phase One and Phase Two of the HS2 scheme. As these will be procured separately the risks associated with each have also been determined separately. However, to reflect the fact that lessons will be learnt from the first phase the level of risk is significantly lower for Phase Two.

4.6.5 The QCRA simulation produces a range of possible estimates for contingency as a percentage of the base cost. These values are displayed in an S-curve in Figure 4. The S-curve shows the probability that a given cost will not be exceeded e.g. the P95 cost has a 95% chance of it not being exceeded.

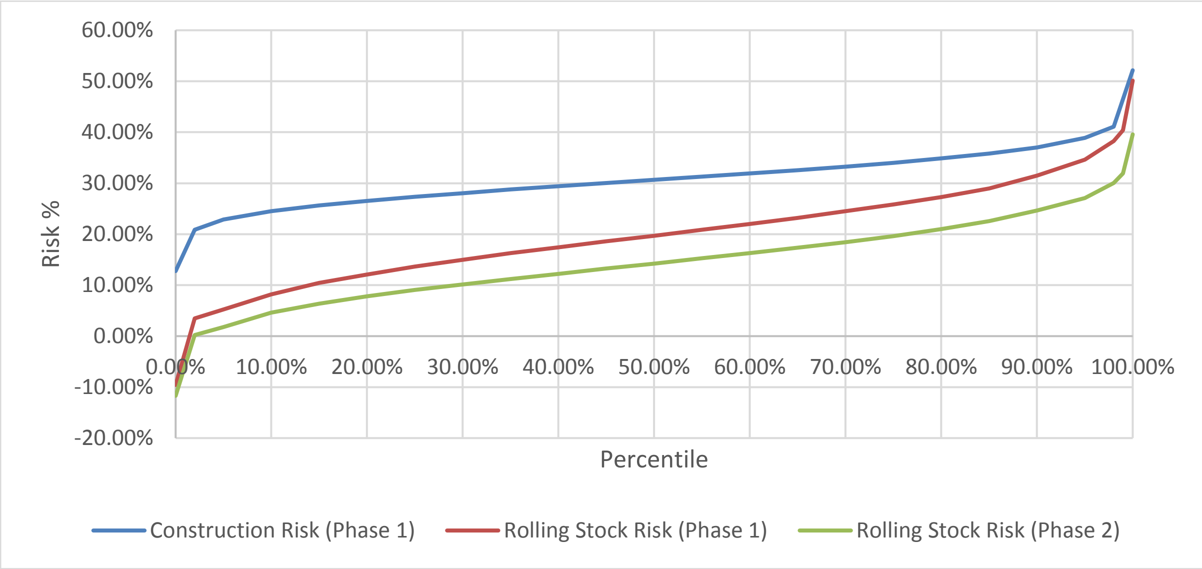

Figure 4: Quantitative Cost Risk Assessment (QCRA)

5 Glossary

Definitions	Acronym	
Appraisal period	-	The assumed useful life of the assets for analysis.
Benefit cost ratio	BCR	The ratio of project benefits to project costs.
Capital costs/capital expenditure	CAPEX	The cost of acquiring the physical assets for HS2, including construction, land purchases and rolling stock.
Cost benefit analysis	CBA	The process of calculating and comparing the benefits and costs of a project, usually to generate the BCR.
Consumer price index	CPI	A measure of inflation, currently adopted as the government's official measure of price increases.
Demand cap level	-	The level of long-distance demand at which demand growth is assumed to halt.
Do-Minimum	DM	The set of train services and demand which are assumed to be in place if HS2 did not happen – the base case – against which the Do-Something is assessed.
Do-Something	DS	The transport intervention – HS2 scheme – being considered.
Department for Transport	DfT	The government department responsible for the English (and some of the Scottish) transport network.
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.
Green Book	-	HM Treasury's guidance for public sector bodies on how to appraise proposals before committing funds to a policy, programme or project.
Optimism bias	OB	A financial allocation to compensate for the systematic tendency for appraisers to be over-optimistic about key project parameters.
Office for Budget Responsibility	OBR	An independent body that analyses the UK's public finances.
Office of National Statistics	ONS	The UK's largest independent producer of official statistics.
Operating Costs/Operating Expenditure	OPEX	The costs associated with running the railway including the maintenance of the track and trains and staff costs.
PLANET Framework Model	PFM	The suite of models used by HS2 to analyse the impact of HS2 on 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. Phase One includes stations at London Euston, Old Oak Common (West London), Birmingham Interchange (near the National Exhibition Centre and Birmingham Airport) and Curzon Street.

Definitions	Acronym	
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.
West Midlands to Crewe (Phase 2a)	-	The section of HS2 between the West Midlands (Fradley) and Crewe.
Quantified risk assessment	QRA	A formal method of calculating the quantity of individual risks.
Real terms	-	The financial value, after removing the effects of inflation.
Released capacity	-	The availability on the classic 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.
Service specification	-	The train service assumptions used in our modelling.
Skew		A measure of the asymmetry of the probability distribution.
Standard Deviation	S.D.	A quantity expressing by how much the members of a group differ from the mean value for the group.
Strategic Outline Business Case	SOBC	
Sunk cost	-	A cost that has already been incurred and cannot be recovered.
Train operating companies	TOC	A company that holds an operating contract for a rail franchise.
Value of time	VoT	The implicit value people place on time
Web Based Transport Analysis Guidance	WebTAG	The DfT's guidance that provides guidelines on how to conduct transport studies.
Wider economic impacts	WEIs	The agglomeration, imperfect competition and Increased Labour force participation benefits.