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To: Lee Taylor

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Subject: Peer Review of High Speed 2 Wider Economic Impact Assessment with a S-CGE model, provided by PWC on behalf of HS2 Ltd.

1. Introduction

This paper presents our peer review of the PricewaterhouseCoopers LLP (PwC) report to High Speed Two Limited (HS2 Ltd): *High Speed 2 Wider Economic Impact Assessment with a S-CGE model* (PwC, March 2022). Our focus is primarily methodological. The appropriateness of the model, the model structure and how the model has been 'shocked' are of primary interest.

This peer review report was drafted in November 2021, and subsequently updated in March 2022. In between these dates some nomenclature and presentational changes were made to the PwC report. Our peer review report retains the original nomenclature. For reference:

- *Phase 1 & 2a* is refered to as **Network S1** in this report
- *Phase 1, 2a and 2b Full Network* as **Network S3** in this report
- The *incremental benefit of Western Leg 2b* is referred to as **Network S2** in this report

For the update to this peer review report we have not been provided with any revised detail behind the headline modelling results. The numbers (where quoted) in this report therefore refer to those provided for the November 2021 peer review unless otherwise stated. In almost all instances, as far as we can tell from the headline numbers presented in the PwC report there has been no substantative change, with small changes resulting from varying the time span over which cumulative values are calculated.

Our review comprises the following sections:

1. Multi-regional Input-Output tables
2. Channels for economic growth
3. The S-CGE model
4. Productivity shock inputs
5. Spatial and industrial disaggregation
6. Rational expectations
7. Welfare analysis
8. Appraisal period parameters
9. Summary

2. Multi-Regional Input-Output Tables

As we understand it, deriving the multi-regional Input-Output (IO) table is essentially a four-step approach:

1. The base UK IO table is adjusted with data from sources such as the Annual Business Survey, gross value-added shares in each region and tax data.
2. Initial assumptions for coefficients are:
    - Input structure for industries not differentiated by region.
    - Output structure for all industries not differentiated by region.
3. Changes to the above based on industry location quotients and inter-regional distance weighting.
4. Cross-entropy method for final balancing.

The procedure accords with standard practice when empirical multi-regional IO tables do not exist. Note, however, that although location quotients and distance weighting are reasonable representations of reality for goods and personal services, they may be very approximate for remote services such as finance and information technology.

The industry split and regional disaggregation, especially the former, are not the most appropriate for studying the wider economic effects of HS2. We discuss this further in Section 5.

3. Channels for Economic Growth

The main channels by which HS2 would impact on the economy in terms of pure growth are captured in the modeling system. Business User benefit and agglomeration impacts are used as inputs into the model, whilst the induced investment and labour supply is modelled endogenously via the consumption-leisure model.

There is no feedback loop from the Spatial Computable General Equlibimrum (S-CGE) Model back into the transport model. Thus there could be some additional second order impacts – these could be either positive or negative. Positive ones would be where induced development fosters further clustering and agglomeration impacts, and negative ones could be where congestion effects from said clustering may crowd out some of the growth. We would, however, expect these effects to be second order.

The consumption-leisure model controls labour supply. This model is required to soak up all the differing responses by the labour market in terms of working more hours, commuting between regions and migration. This is obviously limiting if some of these responses are of policy interest – which they are in the case of HS2.

The representation of the channels by which regional re-allocation of activity (i.e. displacement) is captured is more mixed. Competition type effects are captured, but migration by firms and households, and commuting by households are not explicitly modelled, and the potential re-distribution effects on the tourism/leisure sector are not either. Hence reallocation of activity is implicit, but not much can be inferred about the mechanism or whether the overall scale is correct. The absence of an explicit migration model also means that it cannot capture the bell-shaped curve of dispersion that New Economic Geographers argue exist. For example, if HS2 leads to Manchester importing more goods and services from Birmingham this could be because:

- Manchester has attracted more people to live and work there.
- People who lived in Manchester, but now commute to and work in Birmingham spend some of their income in Birmingham (so the Manchester resident is consuming goods from Birmingham).
- Moving goods from Birmingham to Manchester is relatively cheaper than before HS2.

The PwC report makes numerous references to modelling the impacts of dynamic clustering. The model captures the general equilibirum effects (changes in allocative efficiency) of activity changing location, but does not model the agglomeration spin off benefits of any accompanying changes in land use. It is the latter which DfT's Transpot Analysis Guidance (TAG) refers to as dynamic clustering. The model does not therefore model dynamic clustering as TAG defines it (despite the report appearing to suggest that it does).

The lack of localization agglomeration economies and the lack of a migration model means that the model is not therefore explicitly able to accommodate the Venables-Rosewell, New Economic Geography influenced, arguments about re-location of economic activity to the north – a key part of the levelling up agenda, although some is implicit. Venables's later paper on the welfare benefits of this re-distribution rests on the existence of localization agglomeration economies. How this will impact on the results is uncertain. The GDP impacts on the north may be understated whilst the welfare impacts may be overstated (as the loss of economic activity in the south of England typically has a net productivity

cost). Recent work by Dr David Pierce at Instiute of Transport Studies (ITS) as part of his PhD also indicates the localization clustering benefits might not be as large as may have been hoped (although in an application of Northern Powerhouse Rail).

Bringing this together, the structure of the model means it is stronger at modelling the pure growth, i.e. total economic impact type effects, than on the regional disaggregation of that growth. A more developed regional modelling approach could change the results in either direction. It could lead to the model predicting more centralization around London or conversely more dispersion of economic activity to the north (levelling up). We cannot say.

Table 1: Transport-Economy Channels modelled in the PWC S-CGE Model of HS2

Channels		Included in modelling framework	Commentary
Direct cost reduction to and increased productivity of travellers (Business User Benefit)		✓	This is typically expected to be the largest economy shock delivered by transport projects. External input to the model derived from the Planet Framework Model. The latter assumes fixed land uses.
Agglomeration		✓	Urbanisation agglomeration elasticities applied as per the Department for Transport's (DfT's) Wider Impacts in Transport Appraisal (WITA) tool. Localisation agglomeration economies, as per the Venables and Rosewell HS2 arguments, are not captured.
Labour supply (choice between activity and inactivity)		✓	This is captured through a consumption-leisure model. Regional labour markets individually identified and industrial sectors separately identified. Regional labour markets are assumed to be in equilibrium, so whilst unemployment can provide some short term capacity to supply labour, in the medium to long run the model reverts back to the starting position of unemployment.
Induced development		✓	A key component of the S-CGE model is investment
Displacement	Tourism/Leisure	X	HS2 will impact on the leisure sector by influencing choices of destination – with areas of improved accessibility winning at the expense of other regions. There will also be a re-distribution of expenditure in the leisure sector as day return trips become possible; i.e. shift away from overnight stays. The classic High Speed Rail examples of this are Nice on the TGV network in France and Toledo (Spain). Arguably the cities served by HS2 are not directly comparable to Nice or Toledo, but there are still very likely to be changes in the leisure sector (consumer services). This is typically viewed as 100% displacement – i.e. a re-distribution effect within GB.
	Migration of firms and households (Move to more/less productive jobs -M2MLPJ)	X	Migration by either firms or households is not explicitly modelled.
	Competition effects between regions	✓	Captured as part of the Spatial GE effect. For example, firms in North West may outcompete firms in London and export goods and services there if they receive a sufficient productivity shock.
	Competition effects between firms for workers	✓	Captured as part of GE effect. Re-allocation of resources (e.g. labour) to the most productive sectors.
Feedback from land use response to transport sector (crowding out due to crowding/congestion)		X	The output from the S-CGE model in terms of revised land uses is not fed back into the transport model in terms to give updated demands and costs. This may underestimate crowding/congestion effects which may crowd out some of the growth, but also may exclude cumulative growth effects through for example increased agglomeration.

4. The S-CGE Model

The S-CGE model is characterised by commonly used functional forms, structure, assumptions and (from those we can verify) parameter values. We cannot see any serious shortcomings of the model itself that would undermine its results.

For earlier runs of the model the solution algorithm had difficulty converging. Colleagues who use the same or similar solution packages tell us that such outcomes are rare and are probably attributable to inconsistent input settings. We trust this discomforting issue has been resolved.

Although converting the business user benefits into labour productivity improvements is a reasonable approach for business travel, it is unfortunate that other types of travel such as commuting and leisure travel were not modelled. That would have involved disaggregating transport industries from the 'Other' industry, which would have been a good idea regardless. Not separately identifying transport industries in a S-CGE model applied to transport questions is unusual.

Overall Result

After numerous exchanges of emails we are more comfortable with the aggregate results once a 'steady state' has been reached. For example in relation to Network S3 (the full HS2 Phase 2b Western Leg Network) in 2051:

- The change in employment (actually hours worked) is -0.105% of GDP
- The change in the capital stock is 0.180% of GDP.
- PWC advise that factor shares for the change in GDP are 62%/38% respectively (though we have not seen that data), implying a change in total factor inputs of 0.003%.
- User benefits plus both types of agglomeration shocks are 0.065% of GDP.
- So the total change in effective factor inputs is 0.068%.
- The change in GDP that emerges from the model is also 0.068%, implying a 'multiplier' of 1.00 – in 2051.

The main explanation for this unexpectedly low result for the impllied multiplier seems to be the fall in total employment coupled with the relatively high labour intensity and high value of marginal product of labour in the industries that are modelled as receiving most of the direct user benefits, namely businesses that use rail for business travel. Note that unexpectedly low GDP impacts in 2051 can still be welfare enhancing – and indeed is so because of the increase in leisure time.

The multiplier of 1.00 in 2051 contrasts with the full appraisal period multiplier of 1.30 (for Network S3) [Table 8.1 in the original report, updated to 1.32 in the new report, which seems to be the result of a change in time span). The multipliers also vary significantly between networks with the largest multiplier associated with Network S2 (the incremental addition to Phase 2b Western Leg). As far as we can ascertain this additionality and variability in the multipliers is being driven by the rational expectations model, which we discuss below and in Section 6.

However, although the aggregate results seem to present an internally consistent picture, the high sensitivity of the results to two key parameterisations of the model is worrying. Our concerns are the effects of the assumption of perfect foresight and the labour-leisure elasticity. We turn to these below.

Perfect Foresight

Dynamic CGE models tend to be either recursive dynamic or embody full intertemporal optimisation – i.e. perfect foresight. The PwC model follows the latter approach. Some models such as MIT's EPPA model can be set to either mode, and testing has demonstrated that intertemporal optimisation leads to higher economic growth – as expected.

The report presents some sensitivity tests which are described as changing businesses' propensity to return capital to owners. However, the annotation in the model output for the sensitivity tests refers to a capital efficiency adjustment, and Appendix C in the report discusses an adjustment cost of capital – a parameter which has a default value of 2.0. They are not the same thing.

In fact what appears to be happening is that changes in business propensity to invest are proxied by changes in the desired rate of return. The higher the desired rate, the lower the investment. Although 0.1 percentage points is a small proportion of the baseline rate of return, which is calibrated to be about 8.5%, it is almost 5% of the baseline growth rate and thus has a compounding effect when applied over several years. Nevertheless, if investment in any year is 5-10% of the capital stock, a 5% reduction for about 14 years (2021 to 2035) would reduce the capital stock in 2035 by only around 5%. Furthermore, it seems that there is no later rebound of investment as firms belatedly (that is relative to having perfect foresight) realise that HS2 is happening. That is, the perfect foresight approach does not just change the timing of investment, it also changes the total quantum of investment – and by a large amount.

In Table 2 the first row (current model) reflects a model position that PwC describe as businesses being 100% confident that the user benefits from HS2 will materialise. The +0.1% and +0.2% tests reflect a reduced confidence that the benefits will materialise, proxied by requiring a higher rate of return. No tests on over-confidence (or mis-placed confidence) have been run. A change of 0.1% to the capital efficiency parameter reduces the estimated effect of HS2 on GDP in 2051 by 33%. See Table 2. Over the period 2021-2059 the reduction is 60%. A change of 0.2% in the parameter leads to even more dramatic effects. These declines are implausibly large in relation to the compounding effect of the change in the desired rate of return.

Table 2: Sensitivity of GDP results to perfect foresight assumption parameter (Network S3) (undiscounted)

	Total GDP. £m, 2015 prices (2021-2059, every 2nd year)	% Difference from current model	GDP in 2051, £m, 2015 prices	% Difference from current model
Cap eff (current model)	54,898		2,507	
Cap eff +0.1% adjustment	22,004	-60%	1,679	-33%
Cap eff +0.2% adjustment	10,426	-81%	1,297	-48%

Note: Data sourced from input spreadsheets provided by HS2 Ltd. Own calculations

Numerical issues aside, some further discussion on the additionality this model gives rise to and the extent to which investment precedes a transport improvement is provided in Section 6.

Labour-Leisure Elasticity

The consumption-leisure (or labour-leisure) equation determines how much a change in wage rates is split between a change in consumption expenditure and a change in leisure time (and thus the change in hours worked). The latter captures changes on both the intensive margin and the extensive margin of labour supply. It soaks up all the differing responses by the labour market in terms of working more hours, commuting between regions and migration. This is obviously limiting if some of these responses are of policy interest.

Like the perfect foresight assumption, the labour-leisure (Lableis) parameter is also very powerful. Changing it from the default value of 0.3 to either 0.2 or 1.0 alters the change in GDP in 2051 by 53% or -41% respectively, with even larger changes when summed over the period 2021 to 2059. Either almost all the GDP benefits are lost or they are almost doubled.

Table 3: Sensitivity of GDP results to consumption-leisure model parameter (Network S3) (undiscounted)

	Total GDP, £m, 2015 prices (2021-2059, every 2nd year)	% Difference from current model	GDP in 2051, £m, 2015 prices	% Difference from current model
Lableis 0.3 (current model)	54,898		2,507	
Lableis 1.0	8,373	-85%	1,485	-41%
Lableis 0.2	10,3267	88%	3,842	53%

Note: Data sourced from input spreadsheets provided by HS2 Ltd. Own calculations.

Employment or hours worked generally respond positively to an increase in income, but here the net effect is a reduction. It has not been within the scope of our review to assess the literature on the consumption-leisure trade off, but a recent article by Bick et al (2018)[1] shows that in richer countries (including the UK) increases in income tend to lead to no change or to an increase in hours worked. Their analysis indicates that internationally hours decrease with income (as per the consumption-leisure model's results), but for high income countries the reverse holds.

The Lableis parameter is the elasticity of substitution between labour and leisure. As usual with constant elasticity of substitution (CES)-type specifications, it enters the utility function in the form (σ-1)/σ and σ/(σ-1), so small changes can lead to large changes in the consumption-leisure mix. An increase of 0.7 reduces GDP by 85%, whilst a decrease of 0.1 increases GDP by about the same amount. The values used in the central model results (0.3) and the sensitivity test parameters were described as plausible values, with the sensitivity tests being described as significant jumps. Such a description appears to imply (to us) within the potential distribution of likely parameters, but probably towards the edges of that distribution. It strikes us that the consumption-leisure model needs to be judged in how well it represents real world conditions. To that extent we return to the Bick et al (2018) paper and judge that there is at least an open question as to whether hours worked will reduce with increases in income. Bick et al.'s (2018) evidence would, taken at face value, suggest not. The lack of ancillary data on employment changes and welfare changes from the sensitivity tests make it difficult to determine what is happening. For example, in the second sensitivity test (row 3 of Table 3) have employment levels increased against the Do Minimum or are they still lower, and either way by how much?

Whilst we are dealing with small changes in total hours worked (arguably marginal changes), the impact they have on aggregate predictions of the GDP impacts of HS2 is large. This does cause some difficulties with interpreting the total GDP forecast. Having said all this, it is likely that overall welfare may not change much, as we expect the first order effect to be a switch between consumption and leisure – which, at the margin, are valued equivalently. However, until welfare values from the sensitivity tests are made available we cannot be certain. We make some further observations on this topic in Section 7 on welfare analysis.

[1] Bick, A., Fuchs-Schündeln, N., & Lagakos, D. (2018). How do hours worked vary with income? Cross-country evidence and implications. *American Economic Review*, *108*(1), 170-99.

Figure 1: Country Specific Elasticities of Hours to Wages

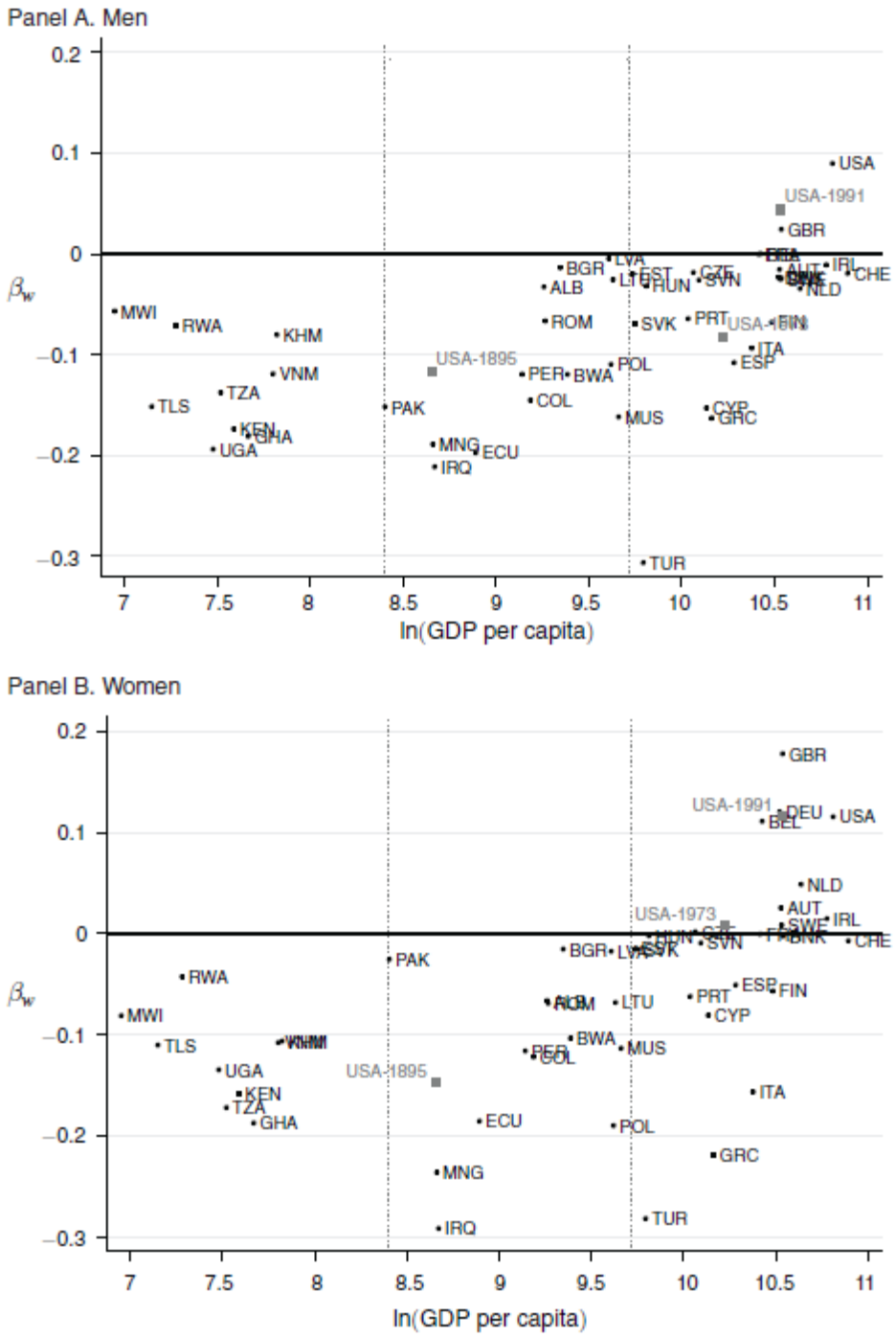

FIGURE 6. COUNTRY-SPECIFIC ELASTICITIES OF HOURS TO WAGES

Notes: The figures show the country-specific elasticities of hours to wages, represented by the coefficient β_w from a regression of individual hours worked on individual wages, controlling for age and age squared. Panel A shows results for a sample of men only, and panel B of women only. The gray data points are corresponding coefficients from US samples of different years (1890s, 1973, and 1991) reported in Costa (2000).

Source: Bick et al. (2018)

5. Productivity Shock Inputs

User benefits (rail and highway) and agglomeration benefits are aggregated to the S-CGE model zones, disaggregated by industry and then used as a productivity shock for the model.

Agglomeration Benefits

For agglomeration benefits these impacts were taken directly from the Department for Transports Wider Impact in Transport Appraisal (WITA) tool and aggregated to the S-CGE model zoning system. The five industrial sector disaggregation in WITA (the fifth being 'other') were mapped onto the HS2 S-CGE model industrial sectors in what looks a sensible manner.

Erroneously labour supply impacts were also added to the agglomeration impacts. Labour supply changes are a change in resources and not a change in productivity. Furthermore the labour supply effects are modelled endogenously. This leads to an average overstatement of the agglomeration benefits by just over 15% for network S3 (i.e. the HS2 Phase 2b Western Leg Full Network), but with significant variation by region – as can be seen in Table 4 below. These agglomeration benefits, however, are just over 20% of the user benefits, so the overstatement in the productivity is more like 2.5% - so not of a scale that will significantly influence the results at a national level. However, they may influence it at a regional level particularly for regions that gain over 'shorter distance' – see the right hand column where the South West, South East and London have an overstatement of agglomeration benefits of 30.6%, 21.4% and 23.9% respectively.

Table 4: Overstatement of agglomeration benefits in inputs to S-CGE model

Region	Aggmoleration benefit, £m, 2015 prices	Agglomeration and labour supply benefits, £m, 2015 prices	Overstatement of the agglmoeration impacts through inclusion of labour supply
East Midlands	7,803	8,476	8.6%
Eastern	28,778	31,653	10.0%
London	41,616	51,565	23.9%
North East	1,544	1,718	11.2%
North West	73,763	86,332	17.0%
Scotland	15,165	15,165	0.0%
South East	36,995	44,909	21.4%
South West	12,113	15,815	30.6%
Wales	3,702	4,149	12.1%
West Midlands	31,812	32,714	2.8%
Yorkshire & the Humber	8,044	9,436	17.3%
Total	261,336	301,931	15.5%

Note: Data sourced from input spreadsheets provided by HS2 Ltd. Own calculations.

User Benefits

As with agglomeration the user benefit shock is converted to a productivity change disaggregated by region and industrial sector.

Disaggregation by Industry

HS2 caters for certain types of trips (passenger trips) and for business trip purposes these are typically only made by certain industries. To understand which industries will gain from the productivity shock provided by HS2, an analysis of National Travel Survey (NTS) data was undertaken. This involved an analysis of the Standard Industrial Classifications (SICs) for business trips by rail greater than 50km.

We have looked at this analysis. The first point to make is that the motivation for doing the analysis and the data source is appropriate and warranted. We would note though that trips and not passenger-kms were analysed. To pro-rata user benefits it should have been passenger-km. The use of trips will bias the analysis if, within the > 50km trip category, there are some industries which travel further than others. This is probably not a significant issue as short distance trips are excluded and it would only be an issue if the industries that travel say 50-75km are very different from say the industries that travel 150km-200km. With passenger-km weighting a trip of 200km would have four times the value of a trip of 50km.

Without further data we cannot offer a view on whether this is a significant impact or not – it is though probably second order on the scale of things. The main point is that the productivity shock for user benefits has been profiled by the industries that use rail services with trip lengths greater than 50km. Thus the industries that use rail services are the ones that are benefiting.

Challenges in shocking the model

We have been informed that a number of challenges were found in shocking the model. A variety of methods were experimented with to solve this. Through testing and exploration it was identified that the problem seemed to stem from large absolute industry productivity shocks being allocated to locations with low concentrations of that industry. The option was to use SIC industry proportions and regional proportions from agglomeration benefits to allocate regional and industry totals and then an entropy method to fit to the pattern of regional/industry activity.

The use of the entropy method to fit the matrix of industry/regional shocks to the underlying profile of industry by region in the UK seems appropriate. We are not expecting HS2 to create new industries where there were none. It creates a new transport market and by doing so boosts existing industries and creates growth. The entropy method therefore seems appropriate.

What we do query is the use of agglomeration benefits as the source of the regional economic impacts, particularly as there was not an attempt to try the 'entropy' method with the regional proportions of user benefits. Previous Economic Cases of HS2 indicate that user benefits are the main source of economic impact – not agglomeration benefits. The data presented in this analysis indicates likewise.

Whether the regional productivity shock for user benefits is allocated according to the regional distribution of agglomeration benefits or user benefits is important. This is because they appear to have different profiles for the different network tests. Basically agglomeration benefits are predominantly driven by the addition of shorter distance services that use the track capacity freed up by HS2. Thus we are in effect using a regional disaggregation of productivity benefits akin to a very large expansion of short distance rail services as the driver to the productivity gain being modelled in the S-CGE model. Such a regional disaggregation is not the same as we would expect for a long distance rail service.

The regional differences between the user benefits and the agglomeration benefits are illustrated in Table 5 and Table 6 below. Here we can see that for the S3 network test (i.e. the HS2 Phase 2b Western Leg Full Network) the regional profiles are similar aside from for East of England, South East and London. It seems that the benefit to London is being spread over London, East of England and the South East.

Table 5: Network S3 – Comparison of Regional User Benefits and WITA Benefits

S3-2041	Regional Allocation	
	User Benefits	WITA
North East	0.7%	0.6%
North West	27.8%	28.6%
Yorkshire and the Humber	1.2%	3.1%
East Midlands	0.3%	2.8%
West Midlands	14.6%	10.8%
East of England	0.9%	10.5%
South East	2.3%	14.9%
London	44.1%	17.1%
Scotland	7.6%	5.0%
The rest of the UK (South West and Wales)	0.5%	6.6%
Total	100.0%	100.0%

Note: Data sourced from input spreadsheets provided by HS2 Ltd. Own calculations.

Table 6: Incremental from Network S2 to S3 – Comparison of Regional User Benefits and WITA Benefits

Incremental from S2 to S3 (2041)	Regional Allocation	
	User Benefits	WITA
North East	2.1%	1.5%
North West	27.7%	46.3%
Yorkshire and the Humber	3.1%	6.6%
East Midlands	0.3%	2.3%
West Midlands	6.7%	10.7%
East of England	1.0%	4.0%
South East	3.5%	6.5%
London	35.3%	6.1%
Scotland	19.3%	10.5%
The rest of the UK (South West and Wales)	0.9%	5.4%
Total	100.0%	100.0%

Note: Data sourced from HS2 input spreadsheets. Own calculations.

For an incremental test from S2 (i.e. HS2 Phases One and 2a) to S3 (I.e. HS2 Phase 2b Western Leg Full Network) we see significant differences between North West, London and Scotland. Here we can see the benefits to London and Scotland are reduced, whilst that to the North West increases significantly. Agglomeration benefits are strong when places that are already reasonably close together are better connected (e.g. see Table 6). Connecting places together that are a long way apart (e.g. London to North West or Scotland) and are still a long way apart after the improvement will not generate many agglomeration benefits, but will generate significant user benefits (if it is a good project) (e.g. see Table 6). This is what is at play in creating the differences visible in these tables.

The diminishing of London's influence in the productivity shock and the increase in the benefits associated with the North West (in the incremental S2 to S3 test) will clearly bias the results for this increment (i.e. the Phase 2b Western Leg) in a regional sense. In fact we see from the regional results presented in the report that London appears to lose GDP as a consequence of implementing Phase 2b (i.e. the incremental impact of extending HS2 to Manchester appears to displace economic activity from London to the North West). This clearly has strong policy resonance with the levelling up agenda and is one of the objectives of HS2. However, given that the regional disaggregation of agglomeration benefits and not user benefits has been used as a productivity shock, and the regional distribution of these are quite different, we find it hard to see how these regional results associated with both GDP and welfare impacts cannot have significant question marks against them. If we are asked to suggest what would make the results more defensible we would suggest:

- Verifying the regional allocation of user benefits against those in the Planet Framework Model, by for example extracting the matrix of user benefits from Planet and then aggregating it directly up to the S-CGE model zones;
- Having confirmed the regional allocation of user benefits as robust (hopefully), using this regional allocation in conjunction with the entropy method to shock the model. The entropy method smooths the regional and industrial productivity gains to match the underlying profile of industry by region and has not yet been applied to the user benefit regional distribution.; and
- Seeing if the results are substantially different from those presented to date.

Total Factor Productivity (TFP) or labour productivity shock

It is our understanding that the model has been shocked as Total Factor Productivity (TFP) by industry and region. This level of disaggregation will importantly pick up the industry and regional impacts of HS2. However, given that the majority of the user benefits derive from improved labour productivity (via journey time savings, comfort benefits and scheduling benefits for example), an alternative and possibly more realistic approach might have been to shock labour productivity only (or in the main). This is interrelated to the discussion on the 'low' GDP multiplier of 1.00 in 2051 in Section 3.

Additional adjustments to the transport inputs

The model requires percentage productivity changes from HS2 in each of the forecast years in 2017 prices. The manner this is operationalized in the model and given the Planet Framework Model (PFM) outputs are in 2015 prices results in (i) a conversion of price levels from 2015 to 2017; and (ii) an

adjustment of the PFM inputs back to 2017 values before being increased in line with GDP/capita back to the forecast year values.

The Business User Benefits from PFM are in the market price unit account (that is represent prices including indirect taxation) and are therefore comparable to the S-CGE model. This is appropriate.

6. Spatial and Industrial Disaggregation

The model contains ten large model zones covering Government Office Regions and eight industrial sectors. This is a consequence of the model functionality, in that with this model structure there is a reasonably tight constraint on the level of disaggregation. It is worth noting that alternative S-CGE models in the literature used for transport applications have a much finer level of disaggregation. For example, the Norwegian national S-CGE model, PINGO, has ninety zones and twenty five sectors and the EC's European model TRIMODE (which covers the UK) splits the UK into thirty two zones and thirty seven industrial sectors.

Clearly the coarseness of the spatial and sectoral disaggregation means that the results lack granularity. Thus a key economic response, the clustering benefits around stations, evidence based on land prices would suggest within 500m of the station, will be missing from the analysis. Benefits to existing users are likely to be adequate, but the full value of the 'induced investment' benefits are not likely to be fully captured due to their highly localized nature.

The limitations on the industrial sector disaggregation also meant compromises had to be made in the model design. Broadly speaking the industrial sector disaggregation splits the economy into users and non-users of the rail system – with the users disaggregated further. The decision making on this would ideally been evidence based, but the timescale of the project meant that an early decision on this had to be made before any empirical work could be done on it. The decision was therefore one based on judgement. Broadly speaking the judgements have been borne out, as despite the 'Other' sector comprising almost 44% of GVA in the UK they obtain only 25% of the GDP benefits (based on a visual inspection of Figure 21 in the PwC report).

Another limitation of the model, vis a vis other models of this type, is that the limited disaggregation options means that the rail industry is not separately identified in the model. Thus the impact of changing levels of expenditure on fares, etc on the rail industry cannot be captured.

7. Rational Expectations

The rational expectations or perfect foresight model gives economic agents perfect foresight and means they start investing in advance of HS2 opening. It has two effects. As discussed in Section 3 it brings forward investment – as businesses have perfect foresight – and it also imparts confidence to invest. Both of these 'behaviours' create additionality. For Network S3 (I.e. the HS2 Phase 2b Western Leg Full Network) the additionality created by this model appears to be in the region of 1.3 for undiscounted benefits. This is because this is the total additionality created by the S-CGE model, but after transitory effects have passed a multiplier of only 1.0 is evident. Thus all the additionality is occurring prior to project opening and this is a consequence of the rational expectations model. We look at this by comparing against what limited, and albeit qualitative, ex post evidence exists. Firstly, we look at the time period of investment and then we look at the additionality question.

Induced investment time period

By bringing forward investment that HS2 would have triggered prior to the opening year of HS2 services creates additional economic impacts as the economic impacts occur earlier and are therefore discounted less in a 60 year appraisal. By having investment in place earlier allows increased economic impact/consumption in future years. There are therefore two issues:

- The rational expectations model impacts on the scale of the economic impact during operation. See Section 3.
- What proportion of the economic impact is brought forward prior to the opening year – as this affects the cumulative economic impact of the project. We comment on this below.

Firstly, looking for evidence on investment being brought forward by transport projects, we see evidence that transport schemes can act as catalysts on investment. The Kings Cross Central development is an example. The increased accessibility from St Pancras International (opening in 2007 at a cost of £800 million) and the re-modelled Kings Cross Station (opening in 2012 at a cost of £550 million) were seen as catalytic to its development. Plans and designs were considered for the site from 1996, with construction starting in 2008, and being completed in 2012. The entire estate of Kings Cross Central is estimated to be £5 billion[2], with the tax payer's stake in the development partnership to be £371 million (valuing the development partnership at approximately £1 billion)[3].

The Economic Case in the HS2 Phase One Full Business Case (FBC) also contains an annex that discusses investment around Curzon station in Birmingham. An important element to note is that some businesses are appearing to be re-locating to Birmingham at the moment, but arguably this is displacement, at a national level, as these companies were arguably in the process of re-locating anyway. Looking at the timelines in the investment around Curzon that is being brought forward (and is therefore additional),

[2] https://www.theguardian.com/politics/2015/aug/17/uk-government-sell-stake-kings-cross-redevelopment

[3] https://www.argentllp.co.uk/media/government-sells-its-investment-in-kings-cross-development

as set out in the HS2 Phase One FBC, this investment is likely to be more closely aligned with the opening of the HS2 project – as per Kings Cross Central.

The main point from this ex post evidence is that economic impacts in advance of the project opening can occur and must be seen as more uncertain than impacts post-opening. They depend on the behaviour and expectations of investors and their attitude to risk. As changes in commercial land values are typically concentrated within the vicinity of the station, we might also expect the induced investment to be occurring there too.

Looking at the results for S3 (which assumes that the Phase 2b Western Leg opens in 2038) we can see from Table 7 pre-opening impacts are 19% of the total impacts of the project (until 60 years after opening) in undiscounted terms, but are 46% of the discounted benefits. There will likely be a similar impact on welfare benefits. It is also clear from the results presented in the report (e.g. the 'hump' graph in Figure 12 in the PwC report) that the model brings forward investment as early as possible – in preliminary results the largest GDP impact occurred two years ago in 2019, though this has been adjusted to 2021 in the latest sets of results.

Table 7: Comparison of GDP impacts pre- and post- opening (Network S3) (undiscounted)

	Total, £m, 2015 prices	Pre-opening 2021-2033		Post-opening 2034-2093	
		Total, £m, 2015 prices	%age	Total, £m 2015 prices	%age
Undiscounted	250,945	48,481	19%	202,464.15	81%
Discounted	87,299	39,930	46%	47,369.76	54%

Note: Data sourced from input spreadsheets provided by HS2 Ltd. Own calculations undertaken as part of November 2021 draft.

It is quite clear therefore that by bringing forward investment, the rational expectations model is having a significant impact on the predicted cumulative economic impacts of HS2, particularly when discounting future benefits.

How realistic is this? This is hard to say. We are not familiar with any literature, beyond the qualitative ex post evidence such as that associated with Kings Central and HS1 stations. Such evidence does not bear out that such large impacts will occur so far in advance of project opening.

Induced Investment Additionality

Our search of the quantitative literature has confirmed PwC's search that little exists on the private sector's response to transport infrastructure aside from an ex post study on the Panama Canal[4].

[4] https://www.idbinvest.org/en/publications/report-infrastructure-investments-and-private-investment-catalyzation-case-panama

Unfortunately, the scale of the investment and the international nature of it mean the results cannot be transferred to HS2.

The previous examples identify that substantial investment can occur in the vicinity of the transport scheme. Some of this will be brought forward and some will be additional.

Confidence is important. The sensitivity tests indicate that the parameter that controls confidence gives rise to great volatility in the model results, as lower levels of confidence are introduced into the model. It is hard to know what level of confidence HS2 will create in the regional economies. However, we do know that not all transport investments are successful. For example, there has been limited induced development from HS1 around Ebbsfleet and Stratford, and from the Channel Tunnel in Ashford. With respect to the Kings Cross Central we can also see that construction only began once St Pancras International was open, though well in advance of the Kings Cross station re-development opening. We also know that regions north of London are characterised by underinvestment. There therefore likely needs to be a significant change in behaviour of businesses outside of London for these levels of investment to occur.

Returning to the question as to what is a realistic level of investment pre-project opening this is a judgmental decision. Different people may hold different judgements. In our view ex post evidence supports private sector actions in advance of the project, probably aligned to when construction begins. Investment is likely to ramp up towards project opening and will not likely complete until several years after opening. We see evidence of continued land use change up to 20 years after opening. This does contrast with the model which allows almost all investment to be brought forward, with a high degree of additionality, with the largest impact in the earliest forecast year in the model.

Our opinion therefore is that the economic impacts (GDP and welfare) prior to project opening should be treated as more uncertain than benefits post-opening. When dealing with discounted benefits, the scale of these pre-opening benefits means that a lot of the total discounted benefits must be treated with a high degree of uncertainty.

8. Welfare Analysis

Welfare methodological observations

Welfare is calculated as the sum of changes in household consumption and leisure time. Investment is excluded. This is the correct approach in obtaining welfare impacts from the model. Investment will in the future generate returns on capital for households, but these will appear in future year consumption (and therefore welfare). In this calculation changes in leisure time (marginal) are valued at the regional wage rate, as would be implied by economic theory.

The S-CGE model includes multiple market failures associated with the government sector as well as a model of imperfect competition. Surpluses associated with these, as would be calculated within a Level 2 appraisal consistent with DfT's Transport Analysis Guidance (TAG), are therefore embodied in the household function in the model. When putting together a full Level 3 appraisal HS2 Ltd/DfT therefore should not add Level 2 wider economic impacts to these values. We illustrate why by briefly discussing the labour supply and move to more productive jobs tax wedge.

If there was no tax on labour earnings, any increase in labour income brought about by greater participation would produce no change in aggregate welfare as the value of the extra income would be exactly offset by the value of lost leisure. GDP would, however, increase. The existence of a tax wedge changes the equation as some of the benefit of people working more hours accrues to the government. Thus the tax paid is an additional benefit that should be included in a welfare metric. The same effect applies if, as result of a transport intervention, a worker moves to a higher paying job in a different industry or different region. What happens to the tax wedge in a S-CGE model? In PwC's model any surplus tax revenue is recycled back to households as a lump sum. Hence the tax wedge is captured in GDP as more consumer spending (or as investment via savings). So, both the change in hours worked and the tax wedge are captured by the model.

The welfare values produced by this study are only comparable to the sum of the business user impacts plus the wider economic impacts in a 'standard' TAG analysis. Impacts on commuters, other non-work trips and external impacts on the environment, safety, health, etc. are not captured in these welfare estimates, nor are the impacts on transport providers (the rail and bus companies). Given the price base of the model, welfare results are in market prices[5] (in TAG terminology) and do not need adjusting. Indirect taxes on fares and fuel costs and switching between heavily taxed and untaxed sectors are not modelled in the S-CGE model and HS2 Ltd/DfT will need to add these impacts on to give a full Level 3 appraisal.

Regional wages (incomes) are used in the model. Therefore the welfare analysis has not been adjusted for income differences. A TAG appraisal uses standard values that do not reflect income differences across the UK. A strict comparison between Level 1 and 2 appraisals based on standard values and this welfare analysis will therefore be difficult. Interestingly this welfare analysis would open up a

[5] However, given that household consumption is composed 100% of sales from industries, it is not clear what is happening with indirect taxes (those in the IO table 4th quadrant)?

distributional analysis using income weights as per HM Treasury's Green Book, which is likely to deflate the London benefits and increase the regional benefits. This might be used to emphasise the levelling up agenda and might be an interesting ancillary piece of analysis that could be done by HS2 Ltd/DfT to give a more complete analytical picture of the distributive benefits of the project.

From the results increased leisure time comprises 40% of utility. This is a significant proportion, but appears to be borne out by the relative valuations of consumption and leisure within the model. It is, however, dependent on the parameterisation of the consumption-leisure model which has been discussed in Section 3. We suspect that the welfare impact of changes to the parameterisation of the consumption-leisure model will have a more muted impact on welfare than it does on GDP – as the model switches households' preferences between leisure and consumption, which at equilibrium have the same marginal value. However, the welfare changes are not reported in the consumption-leisure model sensitivity tests. Nor are they reported in the sensitivity tests for the Rational Expectations model. We think they should be.

From a valuation perspective, two alternative values of leisure have been used in the analysis. The first is the marginal value of lesiure (VoL) is valued at the wage rate (W), and the second is that it is valued at the marginal value of a travel time saving to non-work other trips ($VTTS_{leisure}$). The second valuation is in fact an approximation as the initial leisure valuation is factored down by just under a third. These could be viewed as values within the upper and lower areas of the potential distribution of VoL respectively. It is worth discussing this in more detail.

In equilibrium households optimise the time they spend at work and in leisure, such that there is no additional value in switching time between work and leisure. This leads to the specification that:

$$W = VoL \quad (1)$$

However, (1) assumes that workers are neutral to whether they spend time at work or not (other than the lost leisure time). In fact they may derive utility from spending time at work (e.g. some social status) or they may experience dis-utility (e.g. lack of social status). Thus (1) would be extended to:

$$W = VoL - (dis)utility\ of\ work \quad (2)$$

In this context, though the social value of spending less time at work is equivalent to the sum of the VoL (spending more time in leisure) and the benefit of spending less time at work (if being at work creates disutility). This would be equivalent to the wage (W).

Finally, we are dealing with post tax income to households, as workers make decisions regarding the work/leisure trade off on net of tax incomes (W'). Thus in a real world situation this would be extended to:

$$W' = VoL - (dis)utility\ of\ work \quad (3)$$

Bringing these arguments together, would suggest that the value of reducing hours at work and increasing hours at leisure should be valued at post-tax wages (Eqn 3).

There is a small theoretical and empricial evidence base in the transport economic time use literature on the VoL and its relationship with the wage.[6] Unfortunately, there is a lot of variability in that evidence. With some estimates suggesting VoL is slightly greater than the wage (i.e. workers derive utility from being at work)[7], and others suggesting it is substantially lower (at 58% of the pre-tax wage[8]). Typically these values have been estimated to small samples (e.g. 150 workers) and may not therefore be reflective of the full working population. Furthermore, it is not clear from these papers which of them consider gross income (pre-tax) and which papers consider post-tax income. Furthermore, we are also interested in the value to the individual of spending more time in leisure and less time in work – so it is not just the pure VoL we are interested in, but the sum of the VoL minus the (dis)utility of work.

Turning now to the alternative of valuing leisure by using the marginal value of a travel time saving to non-work other trips ($VTTS_{leisure}$). Here the $VTTS_{leisure}$ is the value of transferring time spent travelling to engage in a non-work other leisure activity to pure leisure. That is:

$$VTTS_{leisure} = VoL - VTAT \quad (4)$$

Where *VTAT* is the value of time assigned to travel

Where travel time is completely unproductive – that is no useful activities can be engaged in whilst travelling then *VTAT* would be zero and $VTTS_{leisure} = VoL$. If however some useful activities can be undertaken whilst travelling (e.g. conversing with fellow travellers, reading or using a phone) then VTAT would be positive and $VTTS_{leisure} < VoL$. Conversely, if the journey not only did not permit any productive use of time, but was extremely uncomfortable (e.g. standing in very overcowded conditions) then VTAT would be negative, and $VTTS_{leisure} > VoL$. Clearly therefore it becomes an empirical matter as to the relationship between $VTTS_{leisure}$ and *VoL*. A further complication is that $VTTS_{leisure}$ is an average for the travelling public, which includes the economically inactive. As the time budget constraint typically binds tighter for the economically active then we would expect the VoL for economically active to be higher than that for the economically inactive. In the HS2 appraisal it is the economically active whose value of leisure it is that we seek. If focusing on the economically active it might be thought that *VTTS* of commuting would be a better approximation. However, this still is problematic. This is because $VTTS_{commuting}$ depends not only on the VoL but on the VTAT of travelling (and travelling during peak hours is typically much worse than in the off peak). Thus the VTAT is very likely to be negative for the commute trip.

It is hard to give a definitive opinion on the appropriate value to allocate to a reduction in work hours and an increase in leisure time. To a certain extent it is an empirical matter. The above arguments can be seen to suggest that a value at the high end of the distribution would be the wage (gross of taxes), and one at the lower end of the distribution would be $VTTS_{leisure.}$. Wages net of taxes would likely lie in the middle of this range.

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[6] Jara-Diaz, S., 2020. Transport and time use: The values of leisure, work and travel. *Transport Policy*, *86*, pp.A7-A13.

[7] Jara-Díaz, S.R., Munizaga, M.A., Greeven, P., Guerra, R. and Axhausen, K., 2008. Estimating the value of leisure from a time allocation model. *Transportation Research Part B: Methodological*, *42*(10), pp.946-957.

[8] Schmid, B., Molloy, J., Peer, S., Jokubauskaite, S., Aschauer, F., Hössinger, R., Gerike, R., Jara-Diaz, S.R. and Axhausen, K.W., 2021. The value of travel time savings and the value of leisure in Zurich: Estimation, decomposition and policy implications. *Transportation Research Part A: Policy and Practice*, *150*, pp.186-215.

Some sensitivity testing of the results in relation to benefits occuring prior to project opening and the value of leisure have been undertaken. The above discussion on the Value of Leisure would suggest that the sesnitivity test of using the non-work other VTTS for the value of leisure is likely to undervalue the Value of Leisure. This could therefore be seen as a sort of stress test. Of course the discussion also highlights that using a Value of Leisure that is the wage gross of tax is likely to be towards the upper end of the distribution.

With around half the benefits of the project occurring prior to project opening due to the perfect foresight model, the sensitivity test looking at excluding benefits prioir to opening is also of interest. Two different scenarios can be envisaged regarding this test. The one presented in the report in Table 17 takes it that only the Level 3 dynamic benefits that occur prior to opening need to be excluded. This reduces the additionality to the appraisal that the S-CGE model gives down to £27,100 million (full network) from £47,700 million. This scenario takes it that Level 1 and 2 benefits can occur prior to the project opening, as a result of investment decisions being brought forward that are necessary to derive the Level 1 and 2 benefits.

An alternative scenario to this would be that Level 1 and 2 benefits only occur post-opening. This would be consistent with a view that the productivity gains from the time savings HS2 delivers are only felt by businesses once the project has opened. Investment of course can occur in advance of opening, and will give rise to the Level 3 dynamic benefits, along with the general equilibirum benefits of improved allocation of resources between industries. Under this alternative scenario the Level 3 dynamic benefits reduce to £10,800 million (Full Network). We attribute these low Level 3 dynamic benefits to the impact of the consumption-leisure model, on which we have already commented.

Welfare results observations

It is interesting to compare the regional GDP and welfare results. As noted earlier for Network S2 (the Phase 2b increment) there are negative GDP impacts for London. However, there are no negative welfare impacts at a regional level. In fact, London is the largest winner in welfare terms for networks S2 and S3. Whilst this may seem inconsistent, there is an internally consistent story behind it. This is that HS2 shifts economic activity out of London (regional GDP in London falls), but real incomes increase across the board and those living in London (and the North East) are then able to consume more goods and services (albeit more are imported in from other regions) and to have more leisure time. Thus despite economic activity being dispersed from London to the North, there exist substantial welfare gains for London residents.

9. Appraisal Period Parameters

We have two observations on the underlying method and parameters associated with pulling the appraisal together over the project's lifetime.

Background economic growth

The PwC report identifies that background GDP growth is taken to be 2.1% per annum. This is based on an analysis of historic GDP growth between 2009 and 2019[9]. This leads to an inconsistency between the analysis presented here and the assumptions that underpin the Core Scenario in TAG, those upon which the Level 1 and 2 analysis are based and those which were used to develop inputs to the S-CGE model. This is because the Core Scenario in TAG and the Level 1 and 2 analysis is based on the Office for Budget Responsibility (OBR) forecasts.

The PwC model takes as its starting point population and employment data in its base year (2017). The GDP growth that is input to the model therefore needs to capture both population change and GDP/capita change from that point onwards. Looking forward real GDP growth is expected by the Office of Budget Responsibility (OBR) to be between 1.22% and 1.74%.[10] Thus by 2081 the economy is expected to be 2.3 times larger than it was in 2023. This is akin to an average growth rate in GDP of approximately 1.5% per annum. If the economy grew at 2.1% per annum, then in 2081 the economy would be 3.3 times larger than in 2023 – this represents a material difference of about 42%. Over the 60 years the average difference between the two forecasts is about half that at 21%, taking into account discounting then the benefits under the two different growth scenarios are different by about 15%.

That is if HS2 gave rise to a 1% increase in GDP (for each and every forecast year) then a 2.1% growth rate in GDP would give 15% more benefits (60 years discounted) than OBR growth rates. This is quite substantial as it could represent an increase in the BCR of 0.15 (for a transport project that increases GDP by 1% per annum in each and every forecast year).

It is open to debate as to which set of background economic growth forecasts are most 'accurate'. However, TAG guidance is clear on the use of economic assumptions. TAG stipulates that common economic assumptions should be assumed across the different aspects of the analysis. The benchmark comparison should therefore have been undertaken using the OBR forecast, as that is the basis for the rest of the appraisal, with the assumed rate of 2.1% as a sensitivity test. The current GDP and welfare forecasts are not therefore directly comparable to the Level 1 and 2 analysis that has been used as an input to the model and other parts of the Business Case.

The sensitivity analysis of the overall benefits to different appraisal issues (perfect foresight, value of leisure) could be enhanced to include a factoring down of the overall benefits from the S-CGE model to reflect a lower level of background growth.

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[9] https://www.ons.gov.uk/economy/grossdomesticproductgdp/timeseries/cagr/pn2?referrer=search&searchTerm=cagr

[10] Source Tag databook – real GDP column in Annual Parameters sheet

Appraisal Period

The appraisal period is based around the lifetime of the asset being appraised. The default lifetime of a transport asset in the UK is 60 years, though guidance has recently been adjusted to permit lifetimes of up to 100 years. An appraisal period finishes when the asset has no life left in it – which in our case would be after 60 years (with a default project).

With phased projects the appraisal period ends at the end of the asset life of the last phase. Appropriate maintenance and renewals should be costed in over the lifetime, particularly for earlier phases. Costs and benefits that occur prior to project opening should be included in that analysis. The treatment of sunk costs (and benefits), i.e. ones that have already occurred, can lead to some alternative specifications of Net Present Value and Benefit Cost Ratio estimates, with what is recommended dependent on what decisions are required to be made (e.g. justification of sunk costs vs a review of a decision to proceed with additional expenditure or not).

Assuming no analysis of sunk costs, then with respect to HS2, this would imply that the appraisal period for Phases One and 2a begins today in 2021 and ends 60 years after it opens, which is 2088 (with Phase One and 2a opening in 2029). For Phases One and 2a plus Phase 2b Western Leg, the appraisal period would begin today and end 60 years after the Phase 2b Western Leg opens (i.e. in 2097, assuming 2038 opening date for the Phase 2b Western Leg). However, the appraisal period for Phases One and 2a ends in 2081 and for Phases One and 2a plus Phase 2b Western Leg in 2085. The former is 7 years too soon, and the latter is 12 years too soon.

This truncating of the appraisal period also leads to an inconsistency with the Level 1 and 2 analyses, which is something which should be avoided in terms of putting the overall case together. The sensitivity analysis of the overall benefits to different appraisal issues (perfect foresight, value of leisure) could be enhanced to include a longer appraisal period.

10. Final Comments

Our overall view of the S-CGE model is that it is representative of UK conditions and uses established CGE modelling conventions. Of course there do exist alternative modelling approaches within the said 'established CGE modelling conventions', so choices in modelling approach need to be made. Most relevant in terms of choice of modelling approach are the perfect foresight model and the consumption-leisure model. As parameterised they work in opposite directions. The perfect foresight model increases additionality (both in GDP and welfare), whilst the consumption-leisure model reduces GDP, but possibly may not impact significantly on welfare. Our view is that they are likely overly sensitive – that is the consumption-leisure model is suppressing GDP too much, and the perfect foresight model is creating an over optimistic investment scenario and also brings investment forward too far.

This is a judgement based on a limited comparison with empirical evidence. This, plus that the respective sub-models' parameters do not always have a direct economic interpretation, means we cannot ascribe a level of under or over estimation. It is tempting for the analyst and reader to assume that one sub-model cancels the other out. This might be the case in GDP terms, as they work in opposite directions, but we cannot offer an opinion on the likelihood of this happening. However, in welfare terms, if welfare values remain largely unaffected by the consumption-leisure model, then it is more than likely that the welfare results represent an overly optimistic scenario. As an alternative benchmark comparison it would be informative, if at some point in the future, the labour supply element in the model can be dampened to zero or close to zero, and businesses could be ascribed myopic investment behaviour.

In looking at the application of the model to HS2 we see that effort has been made in ensuring that the industries that benefit from HS2 receive the economic gain. This gives confidence. We can also see that the model structure lends itself to capturing overall economic growth. Regional impacts are more difficult to model and are not captured to the same extent. In the model regional growth arises through competition effects – there is no explicit migration model, nor can clustering effects around stations be captured partly due to zonal size and partly due to a lack of feedback to the agglomeration model (i.e. dynamic clustering[11] is not captured).

Turning to the inputs to the model; the use of regional productivity gains based on the distribution of agglomeration benefits, rather than the combined regional distribution of user benefits and agglomeration benefits distorts the regional picture of HS2 impacts. It makes it difficult to place too much emphasis on the regional impacts. This is most acute for the balance of regional growth between London and its immediately adjacent regions for the Phase 2b Western Leg Full Network and between the South East (incl. London) and the North West for the Phase 2b Western Leg as an incremental scheme. In future applications of the model it would be worthwhile investigating alternative mechanisms for introducing the business user benefit inputs to the model (e.g. using the entropy method), correcting the agglomeration benefit inputs to represent productivity benefits only and considering further whether rail business user benefits reflect a total factor productivity shock or a labour productivity shock.

[11] The PwC report makes numerous references to modelling TAG consistent dynamic clustering effects but does not. It models the general equilibrium impacts of changes in the location of economic activity but does not model the spin off agglomeration benefits of such changes.

The welfare analysis has been put together appropriately. There is some uncertainty in the value that should be ascribed to an increase in leisure time. The two values used are likely to lie in the likely upper and lower parts of the distrbution of likely values. In our review we also identified that two other facets of the modelling and appraisal that work in opposite directions. The first is that the appraisal period appears to assume a shorter asset life than sixty years. Extending to sixty years would increase the benefits. The second is that the economic growth forecasts that have been used differ from the lower OBR ones. A benchmark TAG economic appraisal would use the lower OBR ones, and would likely give lower GDP and welfare estimates. The sensitivity testing of the overall welfare analysis to different values of leisure and the treatment of perfect foresight could be enhanced to include the impact of extending the appraisal period, and lowering background economic growth to OBR consistent rates.

Looking forward, the analysis using the S-CGE model provides a unique opportunity (certainly in the context of transport appraisal) to undertake a weighted distributive appraisal – using Green Book distributive weights. Rarely in transport appraisals do we have final economic impacts at a household level, which are necessary to undertake such an analysis. A weighted distributive analysis is one of the ways in which the social value of the levelling up agenda can be better captured in a welfare analysis.