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HEATHROW EXPANSION CBA

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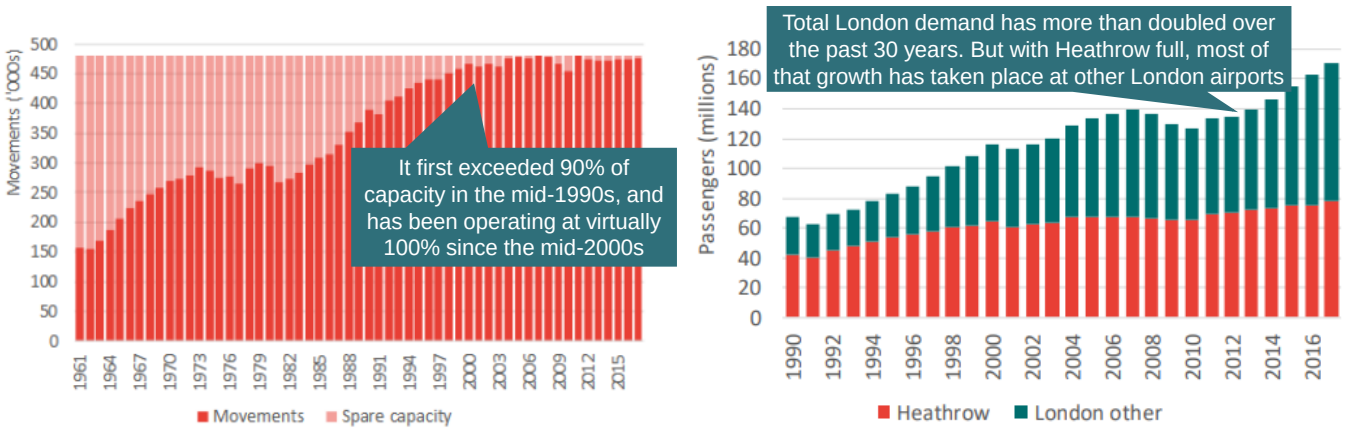
Executive summary

Heathrow has two runways and is limited to 480,000 flights per annum.[1] Prior to the pandemic, it had been operating at virtually full capacity for over 20 years. And it has since returned back to pre-pandemic levels, with a record 83.9m passengers flying in 2024.[2]

Figure 1 Heathrow is full



Source: Frontier analysis based on CAA data

Looking forward, the DfT forecasts that 'unconstrained' aviation demand in the UK will continue to grow with the economy. But, with Heathrow full (and with other airports forecast to also become capacity constrained in the coming years), the DfT forecasts that much of this extra demand may not be met – with as many as 100 million passengers per annum in the UK not able to fly by 2050.[3] This group of unserved demand will be made up of different segments: UK passengers flying abroad, foreign passengers flying to the UK, and passengers travelling for various purposes, including business, leisure, and visiting friends and relatives. Each one of this unserved trips would have its own unique story, representing missed social and leisure opportunities for individuals as well as missed opportunities for UK businesses.

In 2012, the UK government set up the Airports Commission (AC) to explore the topic of airport expansion in the South East of England.[4] In 2015, the AC published its Final Report. It noted

1 This is a planning restriction introduced in 2008 as a planning condition for the development of Terminal 5. Technically, Heathrow could handle more than this cap.

2 https://mediacentre.heathrow.com/pressrelease/detail/21683

3 https://assets.publishing.service.gov.uk/media/5e8dec2786650c18c9666633/uk-aviation-forecasts-2017.pdf

4 Even before the AC, the topic of expanding Heathrow has been discussed by UK government for over 50 years. The Roskill Commission in the late 1960s / early 1970s was tasked with exploring whether an extra runway was needed to serve London demand. In 1990, the UK government commissioned the 'Runway Capacity in the South East Study' (RUCATSE) which found that Heathrow expansion "would afford the greatest benefits." In 2003, the Air Transport White Paper supported a third runway at Heathrow. In 2006, the Government confirmed its commitment to Heathrow expansion, which it repeated in 2009, before reversing its decision in 2010.

the unique role that Heathrow plays in the UK: "Heathrow is best-placed to provide the type of capacity which is most urgently required: long haul destinations to new markets. It provides the greatest benefits for business passengers, freight operators and the broader economy." It also highlighted that spare capacity at other London airports was not a viable alternative: "There is still spare capacity elsewhere in the South East for point-to-point and especially low-cost flights, but with no availability at its main hub airport London is beginning to find that new routes to important long-haul destinations are set up elsewhere in Europe rather than in the UK." And ultimately it made a recommendation that Heathrow should be expanded: "At the end of this extensive work programme our conclusions are clear and unanimous… We have concluded that the best answer is to expand Heathrow's runway capacity".[5] As part of this work, the AC carried out detailed cost benefit analysis (CBA) where it considered a wide range of different cost and benefit types, and also a number of different appraisal methods.

In 2018, the UK government published its Airports National Policy Statement (ANPS) which set out its policy on airport expansion, which included supporting a new third runway at Heathrow. The ANPS was challenged in the courts, but was subsequently confirmed by a Supreme Court ruling, meaning that the ANPS remains official government policy. The next step is for Heathrow to bring forward detailed proposals for a Development Consent Order (DCO).

Heathrow has been exploring different expansion capacity growth scenarios:

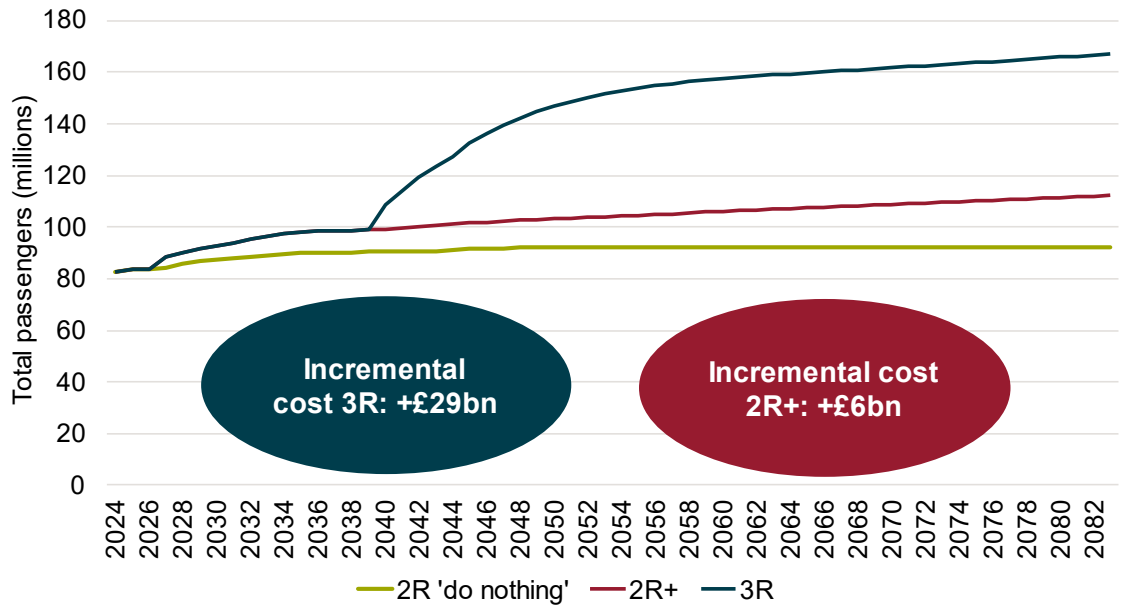
- 2R+: An expansion scenario which involves increasing airport capacity but still within a two runway (2R) airport – i.e. a new runway is not added. This involves renovating and reconfiguring existing infrastructure to help free up extra capacity. Under this scenario, the total number of flights at Heathrow does not increase, but more passengers can be accommodated; and
- 3R: An expansion scenario where a third runway ('3R') is added, in addition to the infrastructure upgrades under the 2R+ scenario.

The chart below – based on June 2024 data provided by Heathrow – shows the passenger and cost forecasts for each scenario, relative to the 2R 'do nothing' scenario.[6] Under the 2R+ scenario, extra capacity is assumed to come into operation within a few years. The cost of the 2R+ scenario covers both operating costs and capital expenditure, and is expressed as *incremental* to the 'do nothing' scenario. Under the 3R scenario, there is a longer construction phase before the additional capacity (on top of the 2R+ scenario) starts to gradually come into operation. The cost of the 3R scenario is also expressed as incremental relative to the 'do nothing' scenario (and already includes costs related to 2R+ infrastructure).

5 https://assets.publishing.service.gov.uk/media/5a808ab4e5274a2e8ab50bd4/airports-commission-final-report.pdf

6 Note that passenger numbers still continue to rise under the 'do nothing' scenario, albeit slowly. In this constrained world, movements are not forecast to increase, but airlines are able to increase volumes by increasing average aircraft size and increasing load factors.

Figure 2 Passenger and cost forecasts – based on June 2024 assumptions



Source: Frontier economics analysis of Heathrow data

Notes: NPVs calculated over a 60 year time horizon, in line with Green Book guidance.

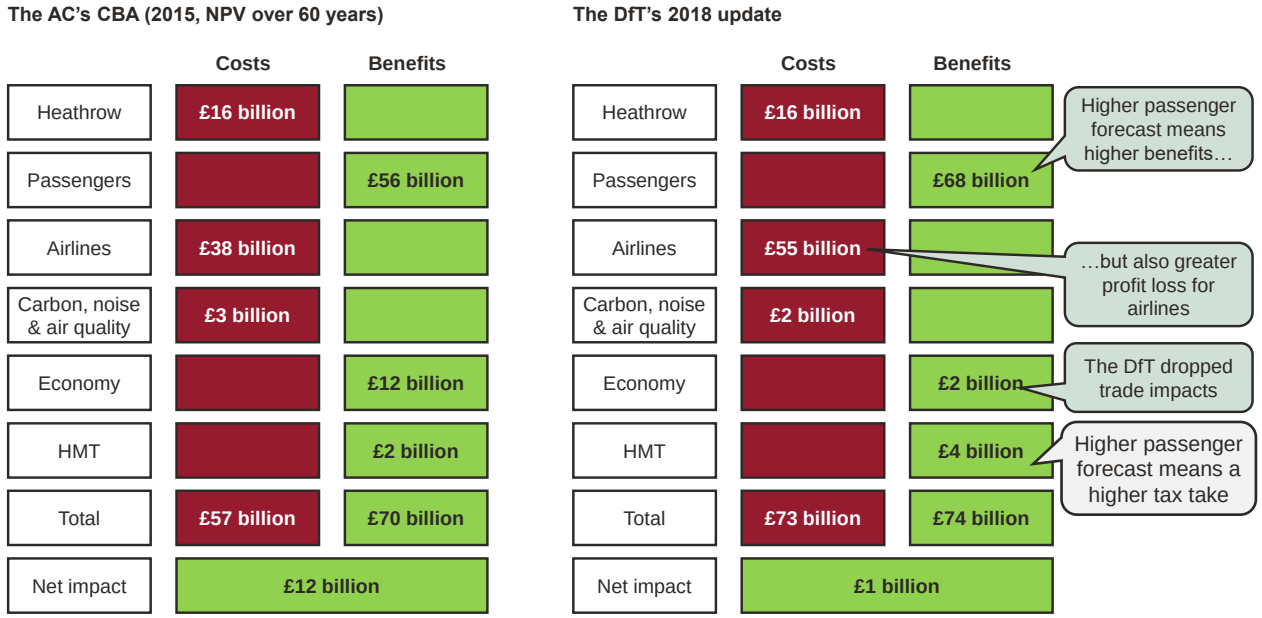
Disclaimer

The analysis in the report was largely based on data from 2024. For the expansion scenarios, we used Heathrow's passenger and cost forecasts based on assumptions from June 2024.

We have been commissioned by Heathrow to consider the costs and benefits of these different expansion scenarios.

Our starting point was to review the AC's CBA, which is a substantial piece of analysis and the most comprehensive attempt at analysing the various environmental, economic and social impacts of capacity growth at Heathrow. The AC's CBA was subsequently updated by the DfT in 2018 when it produced updated UK aviation demand forecasts. Both the AC and DfT analyses found that expansion at Heathrow would lead to positive net benefits for the UK. An overview of their results is shown below.

Figure 3 Overview of the AC and DfT analysis (2014 prices)



Source: *https://assets.publishing.service.gov.uk/media/5b0af93d40f0b673fc7952ed/addendum-to-the-updated-appraisal-report-airport-capacity-in-the-south-east.pdf.*

Note: This is based on the AC's and the DfT's 'carbon traded' scenario. Figures may not add up exactly due to rounding.

The modelling was guided by HMT's 'Green Book' and the DfT's 'WebTAG' which set out best practice for carrying out appraisals. However, these documents are intended to provide high level guiding principles on how to carry out CBA, and understandably they do not provide a detailed step by step guide on how to carry out CBA for every conceivable type of investment, each with their own subtle nuances. The AC noted that it needed to develop new and novel approaches to assess the costs and benefits of airport expansion. Having reviewed the analyses, we agree that there are number of challenging methodological issues with carrying out CBA in the context of airport expansion. In particular:

- What is an appropriate appraisal metric? We agree with the AC and the DfT that a range of different appraisal metrics should be considered to help assess the business case of expansion from different angles, which may involve including or excluding certain costs and benefits depending on the perspective. For instance, as discussed in more detail in the rest of this report, the AC and DfT produced results where construction costs were excluded from the analysis as these would be funded by Heathrow, a privately-owned business, rather than government.
- Many impacts are difficult to estimate robustly, and as such they tend to simply be excluded from the analysis. For instance:
  - Business travel: Expansion can lead to more business travel and help facilitate more trade and investment, which in turn can help boost productivity and GDP in the UK. However, there is no consensus on how these impacts should be estimated, and the

science continues to evolve. The DfT estimated that these benefits could be worth as much as £130 billion (in NPV terms over a 60 year period) – which would have been by far the largest impact in its analysis – but it noted that they are very challenging to estimate robustly. These benefits are challenging to quantify, but they are one of the main reasons for expansion in the first place. To exclude them from the analysis is very conservative and sets a higher bar for expansion to have a positive business case.

While productivity will always be an important metric for policymakers it is worth noting that the UK finds itself with a 'productivity puzzle' – as highlighted by the likes of the Bank of England, the ONS, the OBR, the IFS, and others.[7] The productivity puzzle is based on the observation that UK labour productivity grew at a rate of only 0.6% per annum over the period 2009-2023, compared to 2.2% per annum over the period 1971 to 2007.[8] And this is especially 'puzzling' as other comparable countries, including the US, Germany, and France have not seen such drastic reductions in productivity growth, suggesting that this is a UK-specific problem. As such, infrastructure investments that can boost productivity – including expansion at Heathrow – are particularly relevant.

- Wellbeing: Expansion would result in more passengers flying for leisure and to visit friends and relatives. For instance, this captures passengers flying (to the UK, or abroad) for family holidays, weddings, funerals, and visiting new family members. As noted by the DfT, such travel can boost wellbeing and life satisfaction. But these benefits were not included in the AC and DfT analyses. We recognise that these benefits are challenging to quantify, but clearly they are important, and they are attracting increasing attention from academics who consider that pure 'economic' measures (such as consumer surplus) do not fully capture the benefits. Also, while happiness and wellbeing are clearly important outcomes in their own right, in principle they can also be expected to boost labour productivity. For instance, there is a growing body of literature on the links between holidays and lower rates of burnout. However, clearly it is very challenging to quantify these impacts robustly.

- Environmental costs: The AC and the DfT estimated the cost of expansion, including the impact on air quality and noise, as well as carbon. However, it did not include the impact of non-carbon gases on the environment, where the science continues to evolve. All relevant impacts would need to be captured and appropriately costed in the analysis.

In terms of the analysis that we have carried out, in line with the approach taken by the AC, our analysis is split into two main parts:

7 For instance, see: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/labourproductivity/articles/whatistheproductivitypuzzle/2015-07-07

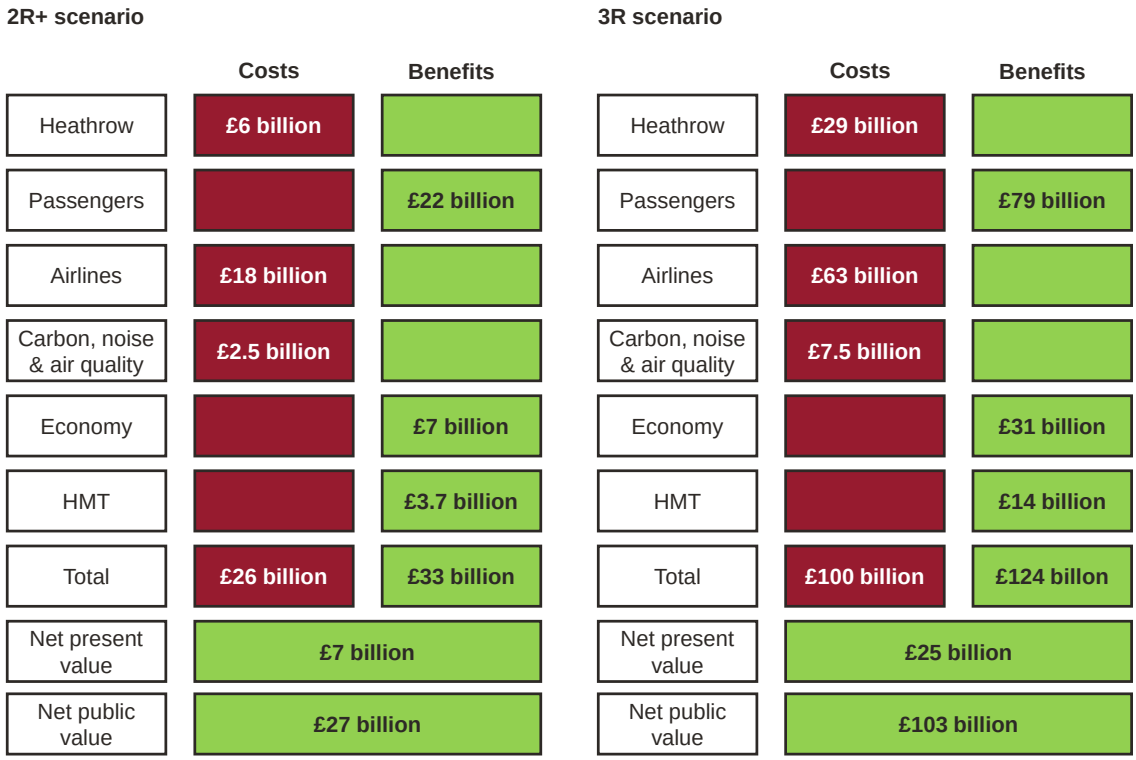
8 https://post.parliament.uk/economic-growth-and-productivity/

- Bottom up: First, like the AC and the DfT, we have estimated a number of different cost and benefit types individually and in isolation from each other and then combined them to produce a 'bottom up' CBA. This is not a formal update of the AC / DfT analysis – especially since many of the models underpinning that analysis are not publicly available. We have estimated some of the costs and benefits ourselves, based on detailed modelling. For others, we take the previous AC / DfT results and carry out high level extrapolations. Further work would be needed to update these other inputs more robustly. We estimate that over a 60 year appraisal period[9], both expansion options deliver significant benefits, and that under both the 'net present value' metric (the broadest considered by the AC) and the 'net public value' metric (excluding construction costs, airline lost profits and taxes[10]) there is a strong case for both options – matching the results previously found by the AC and the DfT.

9 When carrying out a CBA, there is a methodological question around when the 60 year appraisal period should start: should it start 'today' or when the extra capacity comes online (with construction costs incurred before the opening date being rolled forward to the start date)? Given that construction costs are incurred before the extra capacity comes online, whereas the benefits only arise afterwards, the business case would be significantly lower if the 60 year appraisal period starts 'today'. This is because many of the years included in the analysis would cover the pre-opening phases, and hence no benefits are being delivered. Starting the appraisal period from the opening date would lead to a much stronger business case because there would be more years included in the analysis where benefits are being delivered. To be conservative, in this report we have started the appraisal period from 'today'.

10 The AC / DfT did not exclude taxes from the 'net public value' metric. However, as discussed in more detail in this report, in our view, while expansion would generate higher tax proceeds for HMT, tax is technically a 'transfer' from passengers / consumers – i.e. where the transfer benefits one party but comes at a cost to another, leaving society as a whole unchanged in aggregate. Therefore to be conservative we have removed it from our estimates of net public value. However, it is still worth noting that HMT would stand to benefit from a private investment made by Heathrow (and foreign shareholders). Also, while Air Passenger Duty is a transfer from passengers to HMT, expansion would lead to many new foreign passengers flying to the UK, passengers who might not have come to the UK without expansion. Therefore, the APD associated with these passengers can be viewed as being additional from the UK's perspective and new money entering the country.

Figure 4 Overview of our 'bottom up' CBA results (2024 prices)



Source: *Frontier analysis*

Note: *NPV over the period 2024-2083. 'Net present value' and 'net public value' are based on the appraisal metrics considered by the Airports Commission and the DfT. 'Net present value' is the sum of all benefits minus the sum of all costs – i.e. the widest appraisal metric. 'Net public value' essentially asks 'what does the public get out of the investment?'. It excludes (i) construction costs (as these are funded by Heathrow, a private company (with foreign shareholders); (ii) airline lost profits (as these were essentially 'supernormal' profits, brought about by capacity constraints, and many of these airlines are non-UK based with profits taxed in other jurisdictions); and (iii) taxes (as these are a transfer from passengers). Numbers may not add up exactly due to rounding.*

Under both scenarios, we find that ticket price savings are the single biggest impact in the analysis. And including estimates of the wider economic impacts (i.e. the increase in GDP brought about by the increase in trade and investment) increases the net benefits significantly.

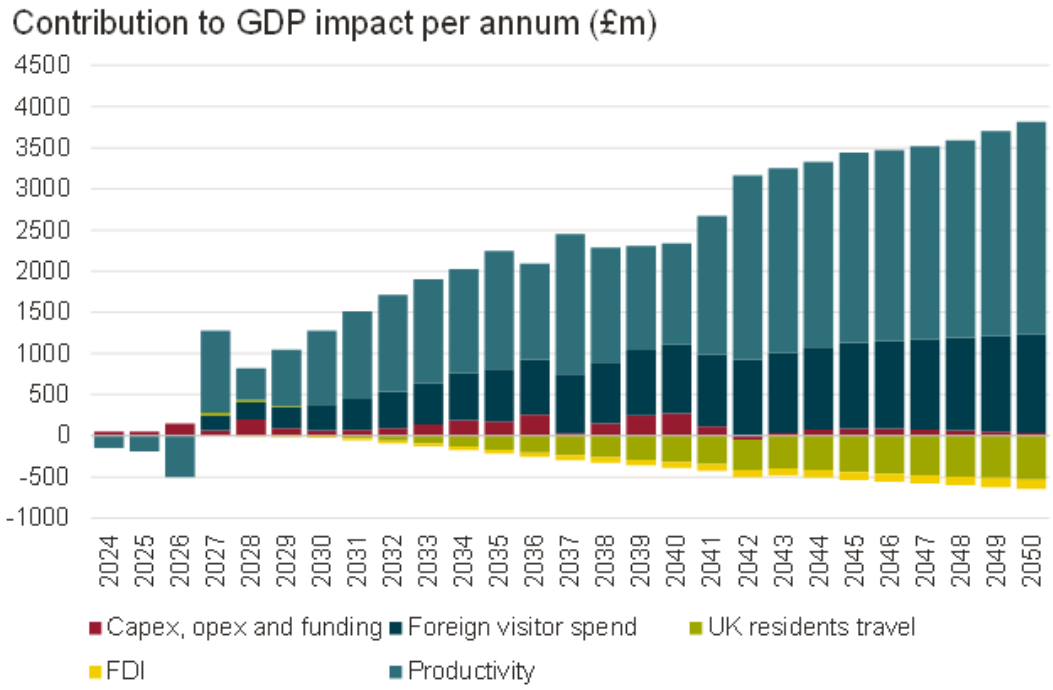
However, we note that our approach to estimating carbon, noise and air quality costs is simple, and only a high level extrapolation of the DfT's estimates.[11] Further work would be needed to produce more robust estimates. However, viewed in a different light, our results suggest that under both expansion options there is a significant positive 'margin'

11 For the 3R scenario, we have conservatively decided to take the DfT's original estimates (uplifted to 2024 prices) and multiple them by x2.5. This captures that the UK government's carbon values are now around 2-3 times greater than the older values assumed in the DfT's analysis. We consider this approach to be conservative, because (i) the DfT's passenger forecast (and therefore associated environmental impacts) ramped up significantly faster than the forecasts currently being considered by Heathrow; and (ii) we have applied this uplift not just to carbon costs, but also to the DfT's estimates of noise and air quality too, as a broad proxy for other impacts. For the 2R+ scenario, we note that the size of the expansion is significantly lower than under the 3R scenario. And therefore the associated impacts would also be lower. We have taken the figure estimated for the 3R scenario and multiplied by 33% - reflecting the lower scale of the expansion option. However, further work would be needed to produce more robust estimates.

(i.e. the benefits minus construction costs minus airline lost profits) remaining to cover environmental costs. And these margins are significantly greater than the environmental cost impacts previously estimated by the AC and the DfT.

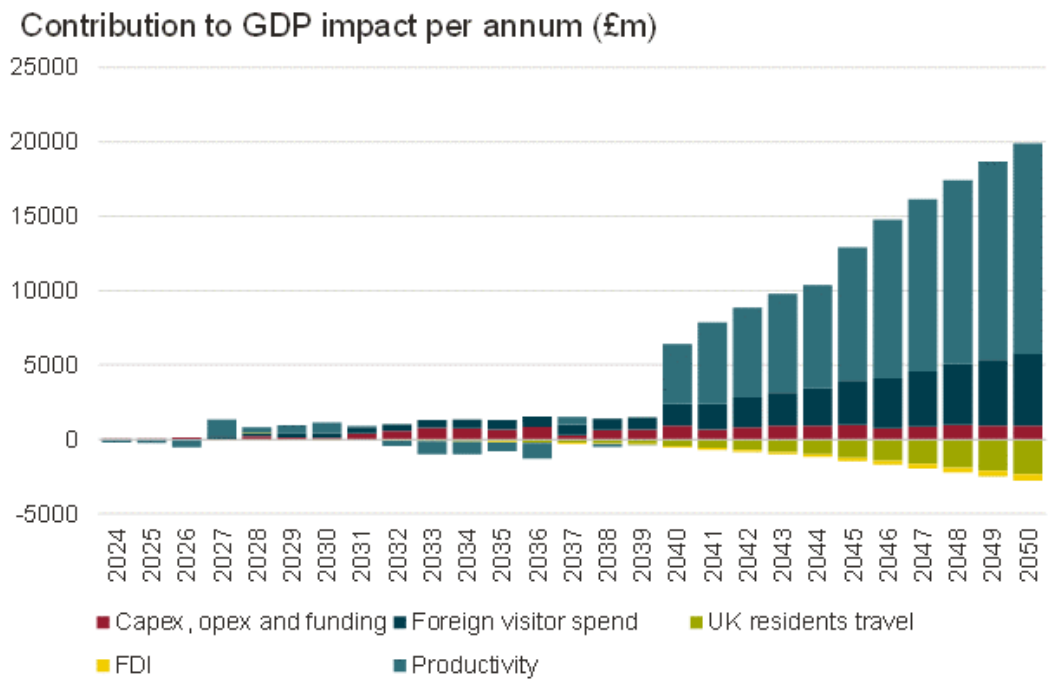
- CGE modelling: Second, like the AC, we have also carried out 'Computable General Equilibrium' (CGE) modelling (in partnership with Centre of Policy Studies (CoPS), Victoria University Melbourne) which assesses more holistically the impact of expansion at Heathrow on the UK economy, as a whole. This modelling takes into account that the economy is made up of a number of interconnected sectors, and how expansion in one sector impacts on others, with a number of first-, second- and third-order impacts. Expansion leads to positive impacts in some sectors ('crowding in') but also leads to negative impacts in others ('crowding out') – e.g. expansion drives up demand for certain factors of production, which are scarce, which increases costs for other sectors. The chart below provides an overview of the results for the different growth scenarios.

Figure 5 Contributions to GDP impacts under the 2R+ scenario



Source: Frontier analysis

Figure 6 Contributions to GDP impacts under the 3R scenario



Source: Frontier analysis

The CGE modelling suggests that both expansion scenarios deliver very positive GDP impacts: +£51 billion under the 2R+ scenario (in NPV terms over a 60 year period) and +£184 billion under the 3R scenario. These numbers are broadly in line with the AC's CGE analysis of the third runway (£127-£247 billion in 2024 prices). Importantly, CGE modelling focuses on economic / market effects only, and does not take into account environmental or social impacts. However, using our high level estimates of environmental, noise and air quality impacts, described above (i.e. £2.5 billion for the 2R+ scenario and £7.5 billion for the 3R scenario), we still see very positive net impacts overall.

Taken together, both pieces of analysis – the bottom up approach and the CGE analysis – suggest that both expansion options would have a very large net positive impact on society.

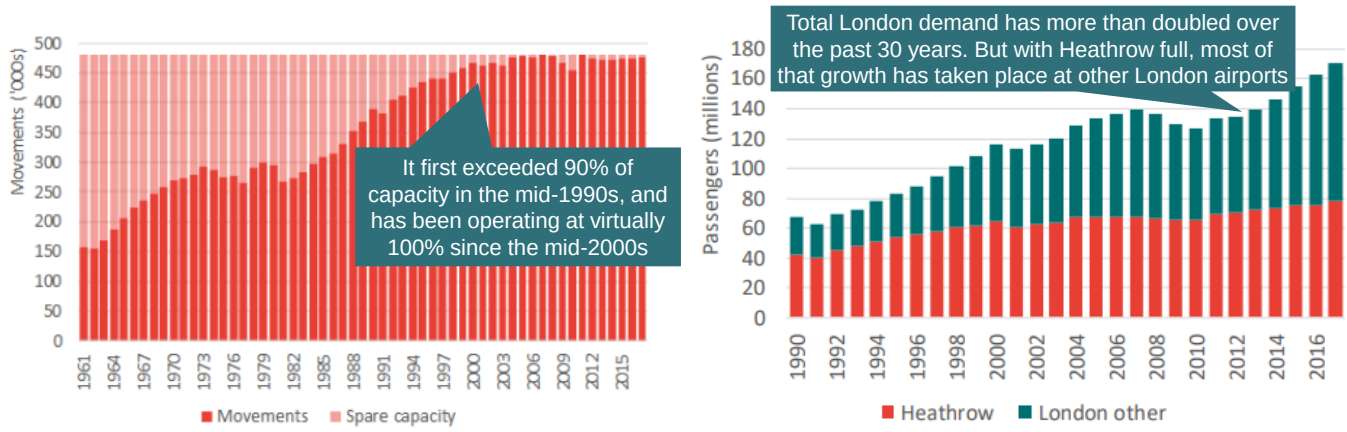
1 Introduction

1.1 Background

Heathrow is full

Heathrow has two runways and is limited to 480,000 flights per annum.[12] Prior to the pandemic, it had been operating at virtually full capacity for over 20 years. And it has since returned back to pre-pandemic levels, with a record 83.9m passengers flying in 2024.[13]

Figure 7 Heathrow is full



Source: Frontier analysis based on CAA data

Since then, total aviation demand in London has grown considerably, but with Heathrow full, most of this growth has materialised at other London airports. Airlines at Heathrow have been able to increase total passenger volumes over time, for instance by deploying larger aircraft, increasing load factors, and switching out lower-capacity short haul routes for higher-capacity long haul routes, but with the total number of flights capped, this constrained growth can only go so far.

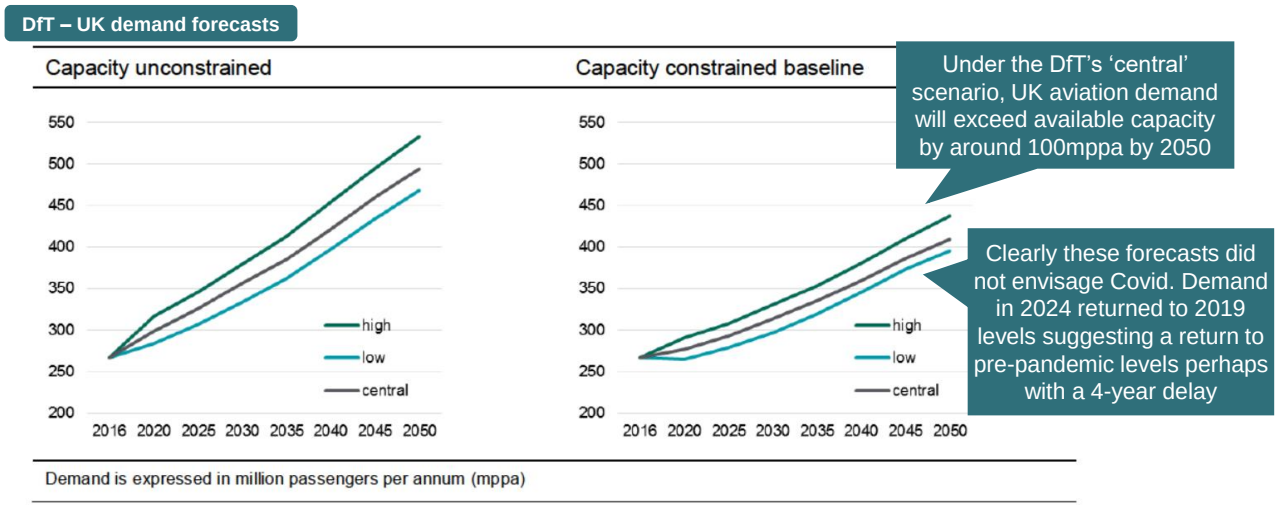
Looking forward, the DfT forecasts that 'unconstrained' aviation demand in the UK will continue to grow. But, with Heathrow full (and with other airports forecast to also become capacity constrained in the coming years), the DfT forecasts that much of this extra demand may not be met – with as many as 100 million passengers per annum in the UK not able to fly by 2050.[14]

12 This is a planning restriction introduced in 2008 as a planning condition for the development of Terminal 5. Technically, Heathrow could handle more than this cap.

13 https://mediacentre.heathrow.com/pressrelease/detail/21683

14 https://assets.publishing.service.gov.uk/media/5e8dec2786650c18c9666633/uk-aviation-forecasts-2017.pdf

Figure 8 UK aviation demand is forecast to continue growing

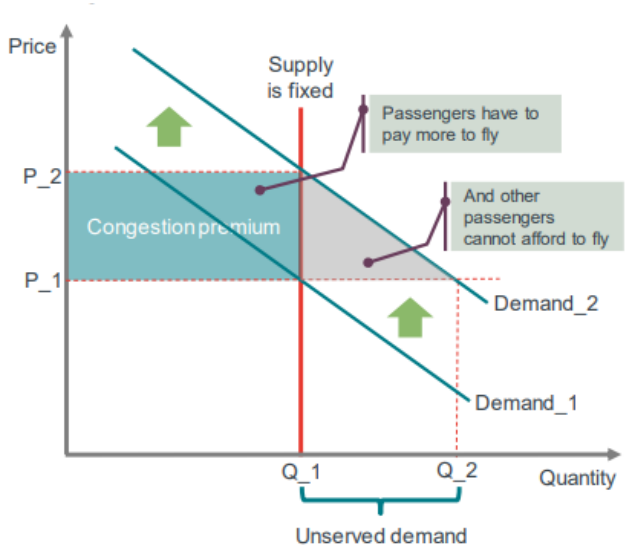


Source: Frontier analysis based on DfT data

Capacity constraints ultimately come at a cost. We expand on these points in more detail in the rest of this report, but at a high level:

- Connectivity is not as strong as it otherwise would be. Airlines at Heathrow can only add new connections if they free up capacity by reducing frequencies on existing routes, or by dropping some existing routes altogether. Many new connections may well be viable – including more connections to the UK regions as well as long haul emerging markets – but with a hard limit on the number of flights they are essentially squeezed out by other more profitable routes.

- When demand exceeds available capacity (and when there are only imperfect substitutes available), ticket prices need to rise in order to price the excess demand out of the market. We refer to this increase in price as the 'congestion premium' (sometimes also referred to as 'scarcity rents' or 'shadow costs'). This dynamic is also seen in many other markets, including tickets for major events. This means that passengers who continue to fly end up needing to pay more to do so.



This dynamic has been recognised by the AC, the DfT and the CAA, with the CAA noting "we consider that it is likely that some airlines are earning scarcity rents *[a congestion*

premium] at Heathrow" and that assuming a premium in the range of "£0.9 billion-£2.5 billion per annum" was "conservative".[15]

- And many other passengers are essentially priced out of flying. While some of them may be able to fly to/from other airports instead (albeit this may be less convenient for them), other cannot. And while this group of 'unserved demand' can do other things with their time and money, flying at Heathrow might have been their first choice. This group of unserved demand will be made up of different segments: UK passengers flying abroad, foreign passengers flying to the UK, and passengers travelling for various purposes, including business, leisure, and visiting friends and relatives. Each one of this unserved trips will have its own unique story, representing missed social and leisure opportunities for individuals as well as missed opportunities for UK businesses.

Clearly, airport expansion can help alleviate these constraints and unlock a wide range of benefits for society. But there are also a wide range of environmental and social costs too, and it remains a politically contentious topic.

Expansion timeline: A recent history

In 2012, the UK government set up the Airports Commission (AC) to explore the topic of airport expansion in the South East of England.[16] The scope of the AC was to "identify and recommend options for maintaining the UK's status as an international hub" and to "assess the environmental, economic and social costs and benefits of various solutions to increase airport capacity". The AC initially considered a long list of potential expansion options, before shortlisting three more detailed proposals: two of them involved expansions at Heathrow and one involved a second runway at Gatwick.[17]

In 2015, the AC published its Final Report, in which it noted the unique role that Heathrow plays in the UK: "Heathrow is best-placed to provide the type of capacity which is most urgently required: long haul destinations to new markets. It provides the greatest benefits for business passengers, freight operators and the broader economy." It also highlighted that spare capacity at other London airports was not a viable alternative: "There is still spare capacity elsewhere in the South East for point-to-point and especially low-cost flights, but with no availability at its main hub airport London is beginning to find that new routes to important long-haul destinations are set up elsewhere in Europe rather than in the UK". Ultimately it recommended that Heathrow should be expanded: "At the end of this extensive work

15 https://publicapps.caa.co.uk/docs/33/CAP1871%20Early%20expansion%20costs%20condoc%20v1.6.pdf

16 Even before the AC, the topic of expanding Heathrow has been discussed by UK government for over 50 years. The Roskill Commission in the late 1960s / early 1970s was tasked with exploring whether an extra runway was needed to serve London demand. In 1990, the UK government commissioned the 'Runway Capacity in the South East Study' (RUCATSE) which found that Heathrow expansion "would afford the greatest benefits." In 2003, the Air Transport White Paper supported a third runway at Heathrow. In 2006, the Government confirmed its commitment to Heathrow expansion, which it repeated in 2009, before reversing its decision in 2010.

17 The AC considered a brand northwest runway at Heathrow, which was proposed by Heathrow Airport Limited (HAL) itself (the 'NWR' option), and an alternative Heathrow expansion option which involved extending the northern runway (the 'ENR' option).

programme our conclusions are clear and unanimous… We have concluded that the best answer is to expand Heathrow's runway capacity".[18]

As part of this work, the AC carried out detailed cost benefit analysis where it considered a wide range of different cost and benefit types, and also a number of different appraisal methods. (This work was subsequently updated by the DfT, with some changes to the methodology, in 2017 and in 2018. We describe this analysis – both the AC's and the DfT's – in more detail in the rest of this report.) However, the AC was clear that there were challenges and limitations with carrying out a complex CBA of airport expansion, and this was not the only piece of evidence it considered when making its final decision. It urged the Government to make an early decision on its recommendations, noting that: "Further delay will be increasingly costly and will be seen, nationally and internationally, as a sign that the UK is unwilling or unable to take the steps needed to maintain its position as a well-connected open trading economy in the twenty first century."

In 2018, the UK government published its Airports National Policy Statement (ANPS) which set out its policy on airport expansion, which included supporting a third runway at Heathrow. The ANPS was subsequently challenged in the Court of Appeal and was deemed to be unlawful because it failed to take into account the UK government's environmental commitments and the Paris Agreement on climate change. However, in 2020, this decision was overturned by the Supreme Court, reinstating the ANPS.[19] As such, the ANPS remains official government policy. The next step is for Heathrow to bring forward detailed proposals for a Development Consent Order (DCO). Clearly, the timeline was delayed by Covid, which introduced uncertainty especially until demand returned back to pre-pandemic levels.

Capacity growth options

Heathrow has been exploring different capacity growth scenarios:

- 2R+: An expansion scenario which involves increasing airport capacity but still within a two runway (2R) airport – i.e. a new runway is not added. This involves renovating and reconfiguring existing infrastructure to help free up extra capacity. Under this scenario, the total number of flights at Heathrow does not increase, but more passengers can be accommodated; and
- 3R: An expansion scenario where a third runway ('3R') is added, in addition to the infrastructure upgrades under the 2R+ scenario.

The chart below – based on June 2024 data provided by Heathrow – shows the passenger and cost forecasts for each scenario, relative to the 2R 'do nothing' scenario.[20] Under the 2R+

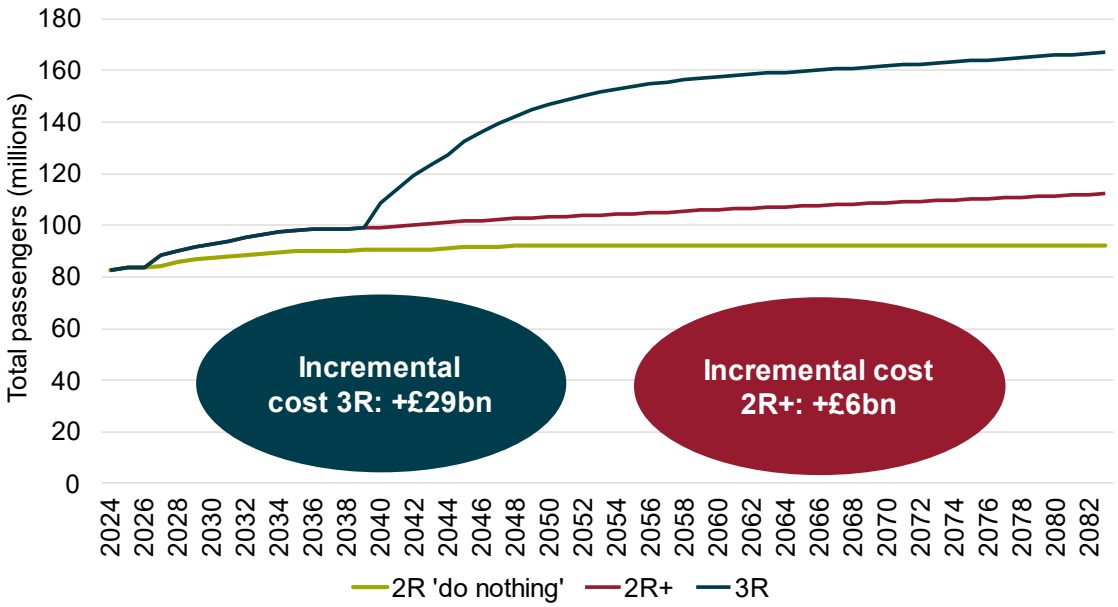
18 https://assets.publishing.service.gov.uk/media/5a808ab4e5274a2e8ab50bd4/airports-commission-final-report.pdf

19 https://www.bbc.co.uk/news/business-55322340

20 Note that passenger numbers still continue to rise under the 'do nothing' scenario, albeit slowly. In this constrained world, movements are not forecast to increase, but airlines are able to increase volumes by increasing average aircraft size and increasing load factors.

scenario, extra capacity is assumed to come into operation within a few years. The cost of the 2R+ scenario covers both operating costs and capital expenditure, and is expressed as *incremental* to the 'do nothing' scenario. Under the 3R scenario, there is a longer construction phase before the additional capacity (on top of the 2R+ scenario) starts to gradually come into operation. The cost of the 3R scenario is also expressed as incremental relative to the 'do nothing' scenario (and already includes costs related to 2R+ infrastructure). (We note that these forecasts were based on planning assumptions in June 2024 and do not reflect any accelerations to the schedule.)

Figure 9 Passenger and cost forecasts – based on June 2024 assumptions



Source: *Frontier economics analysis of Heathrow data*

Note: *Similar to the approach taken by the AC and the DfT, we calculate NPVs over a 60 year time horizon. In line with Green Book guidance, we use a discount rate of 3.5% p.a. for the first 30 years of the period, and then 3.0% p.a. for years 31-60.*[21]

Disclaimer

The analysis in the report was largely based on data from 2024. For the expansion scenarios, we used Heathrow's passenger and cost forecasts based on assumptions from June 2024.

21 When carrying out a CBA, there is a methodological question around when the 60 year appraisal period should start: should it start 'today' or when the extra capacity comes online (with historical costs incurred before the opening date being rolled forward to the start date)? Given that construction costs are incurred before the extra capacity comes online, whereas the benefits only arise afterwards, the business case would be significantly lower if the 60 year appraisal period starts 'today'. This is because many of the years included in the analysis would cover the pre-opening phases, and hence no benefits are being delivered. Starting the appraisal period from the opening date would lead to a much stronger business case because there would be more years included in the analysis where benefits are being delivered. To be conservative, in this report we have started the appraisal period from 'today'.

The scope of this report

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We have been commissioned by Heathrow to consider the costs and benefits of the different expansion options. This is not a formal update of the AC / DfT analysis – especially since many of the models underpinning that analysis are not publicly available. We have estimated some of the costs and benefits ourselves, based on detailed modelling. For others, we take the previous AC / DfT results and carry out high level extrapolations. Further work would be needed to update these other inputs more robustly.

The structure of this report is as follows:

- In Section 2 we provide an overview of the AC's analysis, which was subsequently updated, with some changes, by the DfT. As noted by both the AC and the DfT, we recognise that carrying out CBA of airport expansion is challenging as many of the impacts are hard to quantify robustly and there are a number of methodological issues. We provide comments on the AC and DfT analyses.
- In Section 3 we provide an overview of the different impacts that we have estimated (including the high level extrapolations). In line with the approach carried out by the AC, our analysis is split into two main parts:
  - 'Bottom up' analysis: First, like the AC / DfT, we have estimated a number of different benefit types individually and in isolation from each other. We then discuss how these different bottom up estimates come together as part of an overall CBA.
  - CGE modelling: Second, like the AC, we have also carried out 'Computable General Equilibrium' (CGE) modelling which assesses more holistically the impact of expansion at Heathrow on the UK economy, as a whole. This modelling takes into account that the economy is made up of a number of interconnected sectors, and how expansion in one sector impacts on others, with a number of first-, second- and third-order impacts. For instance, expansion at Heathrow may stimulate other sectors, but as it requires greater use of resources, which are ultimately finite, it drives up costs for other sectors, which may lead to contractions in some sectors. The model seeks to distil the different impacts down into an overall impact on the UK economy. Importantly, CGE modelling focuses only on economic / market effects (e.g. household consumption, trade, investment, exchange rates, and GDP). It does not model non-economic effects such as environmental or social impacts. As such, while there is some overlap between the CGE modelling and the bottom up approach above, they also need to be viewed alongside each other to come to a more complete picture.
- In Section 4 we provide our overall conclusions.

2 Overview of the AC / DfT analysis

2.1 Introduction

In this section we provide an overview of the analysis carried out by the AC, which was subsequently updated, and amended in certain areas, by the DfT. Having reviewed the analyses, we recognise that carrying out CBA of airport expansion is challenging, as it is difficult to estimate many of the impacts robustly. We provide comments on the AC / DfT analyses.

2.2 Overview of the AC analysis

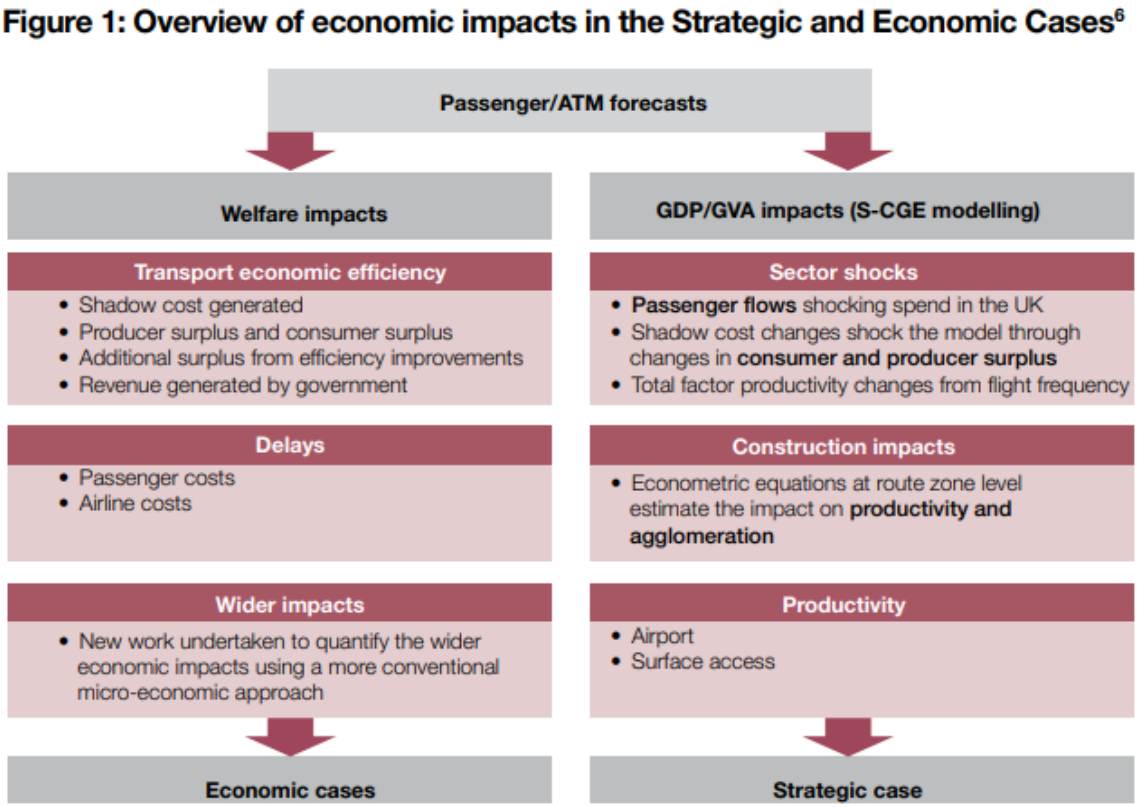
The AC produced thousands of pages of analysis, both quantitative and qualitative, spread out across a number of different reports and annexes. It considered the financial costs of the different schemes, as well as the impacts, both positive and negative, on a range of different stakeholders, including: passengers, airlines, government, local communities, the environment, and the wider UK economy.

As part of this work, the AC carried out two key pieces of analysis:

- Bottom up CBA: It published an extensive CBA where it sought to bring together all the different impacts into an overall appraisal. It described this work as a 'bottom up' approach, i.e. where it considered the different impacts individually and in isolation from each other, before bringing them together into an overall assessment.
- CGE modelling: It also carried out Computable General Equilibrium (CGE) modelling which "provides a stylised representation of the national economy and can be used to analyse how impacts in one sector or region [*e.g. expansion at Heathrow]* affect other areas, showing the scale of potential second- and third-order effects and providing an indication of the impact across the economy as a whole… which are not normally picked up by the conventional economic welfare analysis." Therefore, whereas the CBA described above was more of a bottom up analysis, the CGE modelling was more of a holistic analysis.

The graphic below, from the AC's Final Report, shows a high level overview of the different approaches.

Figure 10 The AC's approach to CBA (welfare impacts) and CGE modelling

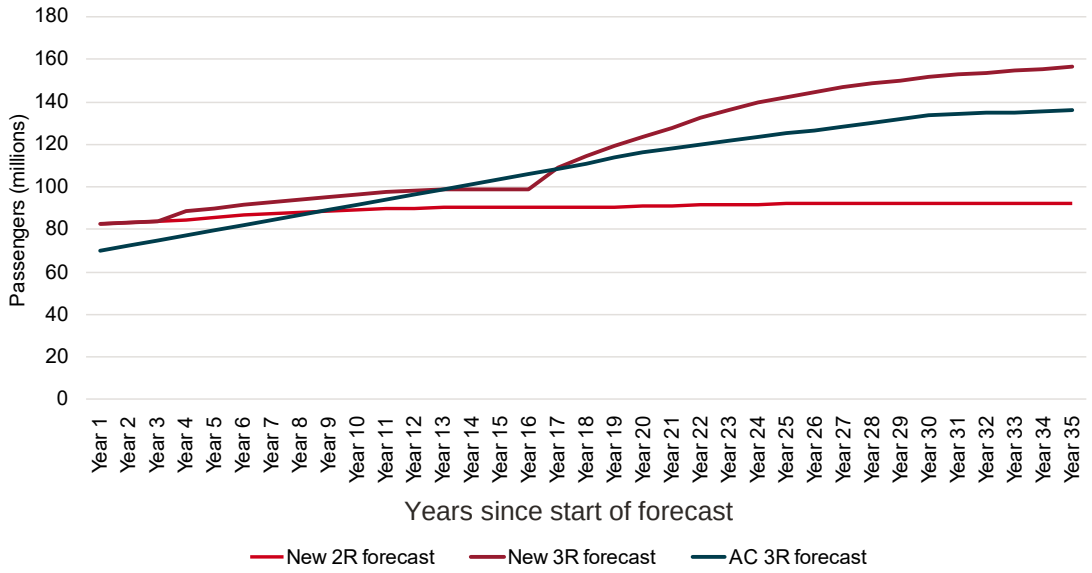


Source: https://assets.publishing.service.gov.uk/media/5a7f718740f0b6230268f872/economy-wider-economic-impacts-assessment.pdf

However, the AC was clear that there were challenges and limitations with carrying out a complex CBA of airport expansion, and these were not the only pieces of evidence it considered when making its final decision. We describe these points in turn.

Also, we note that the AC's analysis was carried out on the basis of older passenger forecasts, now substantially revised since the pandemic. In the chart below, we compare the AC's forecast with the new forecasts currently being considered by Heathrow. The newer forecasts now envisage the ramp up in demand to be slower than that assumed by the AC, albeit the new 3R scenario tops out at a higher level compared to the AC forecast. This makes it challenging to compare results. On the one hand, the faster ramp up in demand under the AC's forecast would suggest the AC's analysis would lead to higher benefits in the earlier years – and earlier years receive a higher weighting in the CBA – but the higher end point under the new forecasts would point to the new forecast delivering greater benefits in the later years.

Figure 11 Comparison of AC and Heathrow passenger forecasts



Source: *Frontier Economics analysis of AC's and Heathrow's forecasts*

Note: *AC forecasts are provided for set yearly intervals (i.e. 2030, 2040, 2050), as such we have interpolated the passenger numbers for the years in between*

2.2.1 The AC's CBA

The AC's modelling was guided by HMT's 'Green Book' and the DfT's 'WebTAG' which set out best practice for carrying out appraisals. However, these documents are intended to provide high level guiding principles on how to carry out CBA, and understandably they do not provide a detailed step by step guide on how to carry out CBA for every conceivable type of investment, each with their own subtle nuances. The AC noted that it needed to develop new and novel approaches to assess the costs and benefits of airport expansion.

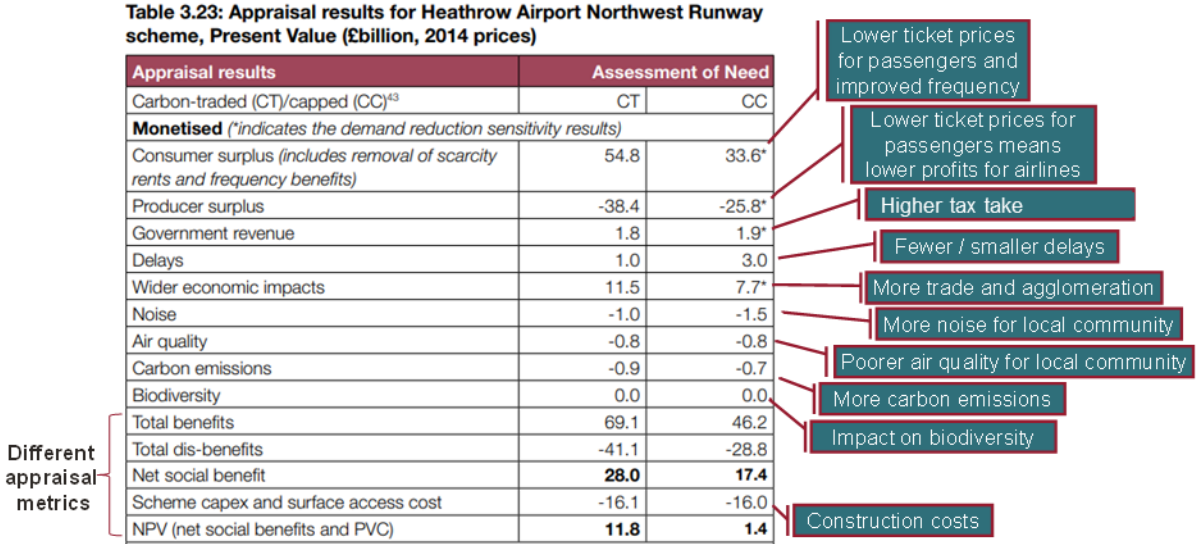
The table below provides a high level overview of the AC's analysis and the different types of costs and benefits that were included. We have also added a high level description for each of the different items included in the analysis. The AC found that, under different carbon policy scenarios[22], and using different appraisal metrics, expansion at Heathrow would deliver positive net benefits. We expand on these points below.

[22] The AC considered two different scenarios: (i) Carbon Capped ('CC') – where UK aviation emissions in 2050 must not exceed 2005 levels, in line with the CCC's recommendations; and (ii) Carbon Traded ('CT') – where aviation emissions can exceed 2005 levels with the aviation sector effectively paying other sectors to reduce their emissions on the aviation sector's behalf. Benefits are higher under the 'CT' scenario because passenger demand is greater

Figure 12 Overview of AC CBA

Table 3.23: Appraisal results for Heathrow Airport Northwest Runway scheme, Present Value (£billion, 2014 prices)

Appraisal results	Assessment of Need	
Carbon-traded (CT)/capped (CC)[43]	CT	CC
Monetised *(*indicates the demand reduction sensitivity results)*		
Consumer surplus *(includes removal of scarcity rents and frequency benefits)*	54.8	33.6*
Producer surplus	-38.4	-25.8*
Government revenue	1.8	1.9*
Delays	1.0	3.0
Wider economic impacts	11.5	7.7*
Noise	-1.0	-1.5
Air quality	-0.8	-0.8
Carbon emissions	-0.9	-0.7
Biodiversity	0.0	0.0
Total benefits	69.1	46.2
Total dis-benefits	-41.1	-28.8
Net social benefit	**28.0**	**17.4**
Scheme capex and surface access cost	-16.1	-16.0
NPV (net social benefits and PVC)	**11.8**	**1.4**
Non-monetised		
Surface access	*Light green*	
Quality of life	*Neutral*	
Community	*Light red*	
Place	*Light red*	
Local economy	Dark green	
Water and flood risk	*Light red*	



Source: *https://assets.publishing.service.gov.uk/media/5a7f4d95ed915d74e6229a2e/business-case-and-sustainability-assessment.pdf*

Note: The appraisal period covered a 60 year time horizon, where future costs and benefits were discounted in line with HMT guidance.

The AC's CBA is a substantial piece of analysis and represents the most comprehensive attempt at analysing the various impacts. Having reviewed the analysis we recognise that there are challenges with carrying out CBA of expansion at Heathrow, and it raises a number of interesting methodological issues, for which there are no single right answers:

- **Private funding:** Expansion would be funded by Heathrow, a privately owned business (with mostly foreign shareholders), whereas the Green Book is "concerned with… the use of *public* resources". Clearly CBA is still relevant as expansion could conceivably leave society as whole worse off, even if it were funded privately. But it is important to note that expansion would not be competing for public funds and it would be Heathrow's shareholders who would be exposed to the financing risks as opposed to government / taxpayers.

  To deal with this issue, the AC noted that the CBA could first be carried out *including* construction costs to understand whether expansion would have a net positive impact on society as a whole, but then having established a positive business case, arguably *excluding* construction costs from the CBA would be most relevant from a government perspective. This lead the AC to consider different appraisal metrics. It considered 'net present value' which was the widest metric it considered, effectively taking all costs and

benefits into account, as well as other appraisal metrics with a narrower focus, excluding certain inputs such as construction costs. The table below shows the different appraisal metrics considered.

Figure 13 Overview of AC appraisal metrics

Figure 9.1 Project appraisal metrics components

	Total benefits to passengers and the wider economy	Net social benefit (AC definition)	Net Present Value	Net public value
Passenger benefits (lower fares, reduced delays and higher frequency of flights)	✓	✓	✓	✓
Government revenue	✓	✓	✓	✓
Wider economic impacts	✓	✓	✓	✓
Environmental costs (noise, air quality, carbon, biodiversity)		✓	✓	✓
Airline profit loss (net of reduced delays)		✓	✓	
Surface access cost			✓	✓+
Scheme cost			✓	
Carbon abatement cost *		✓	✓	

+ Net public value considers surface access costs that might be faced by government. As the determination of who will pay for surface access schemes is yet to be made, this ranges from £0 (if promoters were to pay for everything) to the full cost of all identified surface access schemes.

Source: https://assets.publishing.service.gov.uk/media/5a7f4d95ed915d74e6229a2e/business-case-and-sustainability-assessment.pdf

Note: *As noted in the footnote above, at the time the AC carried out its analysis it was not clear whether government would need to fund any surface access improvements. Based on our discussions with Heathrow, we understand that it would fund any surface access improvements, with no funding required from government. Also, the analysis considered 'government revenue' i.e. tax. Ordinarily, taxes are often not included in CBA as they are essentially a 'transfer' – i.e. they benefit one party (in this case, government) but come as a direct cost to another party (i.e. the parties paying the tax). As such there is an argument that they should be excluded from the analysis. However, from a distributional perspective, it is still worth noting that government was forecast to benefit from higher taxes from what is essentially a private investment.*

Rather than arguing over which appraisal metric is best, this lends itself to a multi-step assessment. First, is there a positive 'net present value' taking all costs and benefits into account? And second, if there is a positive case, what is the 'net *public* value'? (i.e. excluding construction costs and lost airline profits (discussed below)), which effectively asks: what does the public get out of the private investment?

- **Transfers:** A societal CBA focuses on the *incremental* costs and benefits associated with the intervention, and it ordinarily ignores 'transfers' – i.e. reallocations of existing costs and benefits, where one party benefits from the intervention but where this comes as a direct cost to another party. The Green Book notes "Transfers benefit the recipient and

are a cost to the donor and therefore do not make society as a whole better or worse off." However, the Green Book notes that "where distributional effects are relevant, they should be appraised". The issue of transfers appears in a few instances in the AC's CBA:

- Lower ticket prices versus lower airline profits: The single biggest impact (either positive or negative) estimated in the AC's analysis was that expansion would lead to lower ticket prices for passengers.[23] However, the flip side is that lower ticket prices for passengers means a significant reduction in revenue for airlines. For instance, the DfT notes: "When a congested airport expands, the profits of airlines operating out of that airport will be affected as the increase in supply means that they are no longer able to charge passengers the higher fares they were able to charge passengers when the airport was congested". Airline lost profits were estimated to be slightly lower than the ticket prices savings (around 30% lower) because, as the DfT notes, airlines are able to "recoup part of [the lost profits] from being able to serve more passengers once the airport is expanded, and can earn higher fares if the airport becomes constrained again".

  Given that lower ticket prices are technically a transfer from airlines, there is an argument that they should be excluded from the analysis. However, this would essentially ignore one of the key reasons for expansion in the first place. While incumbent airlines may appear to be worse off it is important to note that expansion would simply be returning the market back to 'normal' unconstrained conditions where airlines can expect to earn more modest levels of profitability, rather than benefit from a congestion premium / shadow costs. Similarly, the AC noted: "Aside from such shadow cost revenue, it is assumed that producers… receive no profits over and above the opportunity cost of the capital employed – that is, they would not receive abnormal profits." In other words, arguably the presumption in a CBA is that firms should be expected to earn normal profits. Therefore, even if lower ticket prices are a transfer, clearly from a consumer protection perspective, it would seem preferable for passengers to have lower ticket prices than for airlines to earn higher profits – and this is especially the case when many airlines at Heathrow are not UK-based, with profits taxed in other jurisdictions. Also, this dynamic of increasing consumer surplus at the expense of lower producer surplus is ultimately why we have economic regulation in many sectors, and why the CMA has a duty to have a "beneficial impact on *consumer* welfare".

  The AC included both the ticket price savings and the lost airline profits ('producer surplus' in the results table) in its broadest appraisal metric, 'net present value'. However, it also considered 'net *public* value' where it excluded lost airline profits, as

[23] We note that the AC's estimate of ticket price savings is also an underestimate. Please see text box 1. The AC's estimates of 'passenger benefits' includes ticket price savings, frequency benefits and reduced delays, where ticket price savings amounted to around 90% of the total.

it noted that these may accrue to non-UK businesses, as well as excluding construction costs, as these were privately funded.

- Taxes: The AC estimated that government would generate higher tax revenue following expansion (e.g. with workers moving to higher paid jobs leading to higher income tax proceeds, as well as higher revenue from Air Passenger Duty). However, similarly, taxes are simply a transfer: government generates tax revenues, but these taxes are paid by the public. Therefore, there is an argument that taxes should also appear on the cost side of the CBA, rather than just appearing on the benefit side only. For this reason, it is not clear whether taxes should be included in the analysis. For instance, taken to the extreme, if APD were abolished, ticket price savings would increase even further. The AC's estimate of around £2 billion of tax revenue therefore relates to a level of economic activity that can either be captured by government, as tax, or returned to the public in the form of higher consumer surplus. However, it is still important to recognise that, according to the AC's analysis, HMT also stands to benefit considerably from expansion, and as a privately-funded investment, it would not need to contribute to the cost. Also, while Air Passenger Duty is a transfer from passengers to HMT, expansion would lead to many new foreign passengers flying to the UK, passengers who might not have come to the UK without expansion. Therefore, the APD associated with these extra passengers can be viewed as being additional from the UK's perspective and new money entering the country.

Box 1: The AC underestimates ticket price savings

The AC's estimate of ticket price savings was based on the DfT's aviation demand forecasting models.[24] At a high level, the DfT starts by forecasting unconstrained UK passenger demand at the level of individual UK regions. It then allocates passenger demand to different UK airports, where it aims to allocate passengers to their closest / most convenient airport. However, when an airport becomes full (as in the case of Heathrow), 'shadow costs' at that airport start to rise (essentially higher ticket prices for passengers), meaning passengers will then weigh up whether to travel from other airports instead. For instance, a shadow cost of say £5 at Heathrow may be enough to persuade some passengers to fly from Gatwick instead. However, the DfT understates the true extent of congestion at Heathrow due to how the model is 'calibrated' in the model start year (2016). The model essentially observes that Heathrow still technically had some spare capacity in 2016 (i.e. it was 'only' operating at 99% and not 100.00%) and so it was assumed that there was no congestion in the base year of 2016 and therefore there were no shadow costs estimated for that year. Heathrow is then assumed to become full as demand grows in future – i.e. from 2017 onwards – from which point shadow costs start to rise. In other words, it fails to recognise that Heathrow has been full since the mid-2000s, and therefore disregards all the excess demand (and associated shadow costs) that would have been building up before the model start year.

[24] https://assets.publishing.service.gov.uk/media/668546fa541aeb9e928f43eb/dft-aviation-modelling-framework.pdf

- **UK v non-UK impacts:** CBA typically focuses on the impact of a given intervention within a particular jurisdiction, e.g. within the UK. For many interventions, costs and benefits may be neatly self-contained within a narrow geographic boundary. However, aviation is an international business with cross-border flows and impacts. A third of all passengers at Heathrow are transfer passengers, who may only be passing through the UK, and around half of all O/D passengers are based abroad. Similarly, many airlines at Heathrow are non-UK businesses. Moreover, trade and investment benefits are clearly also two-way, and the productivity benefits associated with extra trade and investment benefit *both* countries (although understandably the AC only focused on UK-based productivity impacts). As noted by the AC, because non-UK passengers and airlines will ultimately make a large contribution to the costs of expansion, and because it is practically impossible to meaningfully apportion costs between UK and non-UK demand, there is a strong case for simply including non-UK passengers in the analysis. WebTag also recognises the challenges and notes: "to ensure internal consistency, the analysis should include all impacts on all affected parties, regardless of origin". As discussed in more detail below, the potential trade and investments benefits could be significant for the UK economy. But they would also benefit the UK's trading partners too – even if this is not included within the scope of the CBA.

- **Many key impacts not included:**

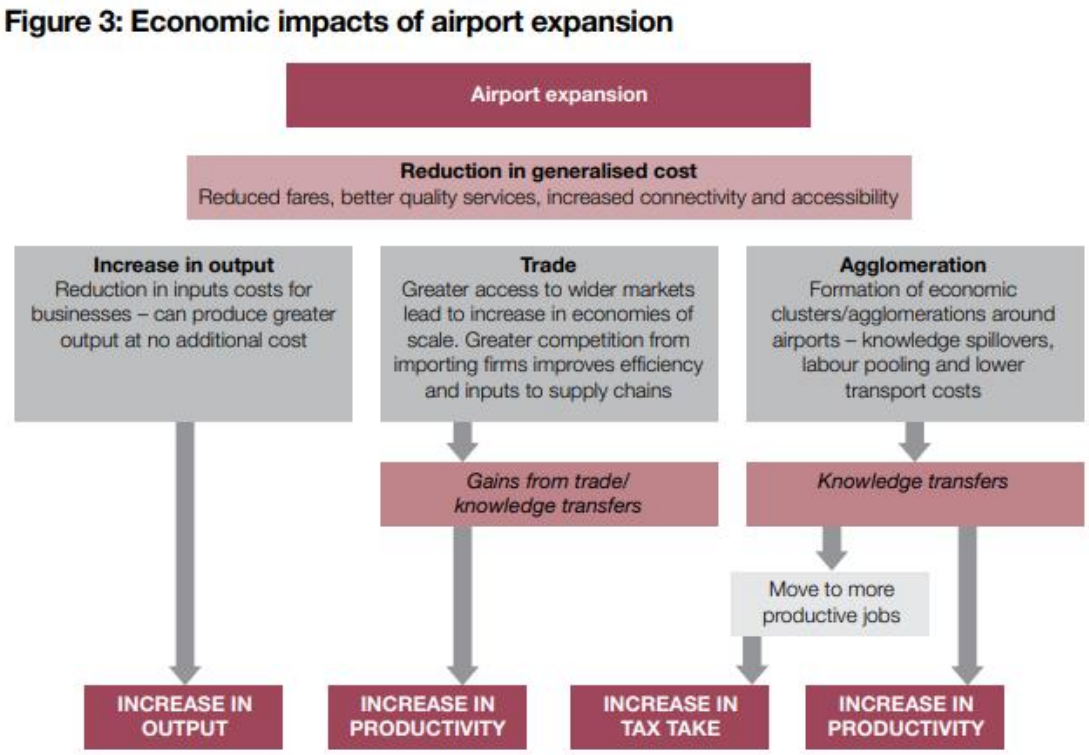
  - Wellbeing benefits from extra leisure and 'visiting friends and relative' (VFR) travel: Passengers who would have flown anyway even under a 'no expansion' scenario benefit from expansion due to lower ticket prices, reduced delays, and improved frequency – as well as reduction in GTC if they are able to travel from Heathrow instead of a less convenient airport. For the extra demand, the AC estimated the increase in 'consumer surplus' – i.e. the difference between willingness to pay and the actual price paid across all passengers, including the extra passengers. However, the benefit of extra leisure and VFR travel is more than just higher consumer surplus or lower GTC. The AC noted that for leisure travel: "The findings demonstrate these patterns of travel are associated with higher levels of life satisfaction, general and mental health, and happiness." The Green Book refers to quality of life and wellbeing: "Social or public value therefore includes all significant costs and benefits that affect the welfare and wellbeing of the population, not just market effects. For example, environmental, cultural, health, social care, justice and security effects are included." Also, while happiness and wellbeing are clearly important outcomes in their own right, in principle they can also be expected to boost labour productivity. For instance, there is a growing body of literature on the links between holidays and lower rates of burnout. However, clearly it is very challenging to quantify these impacts robustly.

    Also, the DfT's aviation demand modelling, which allocates passengers to different airports, arguably suggests that demand is much more flexible (and 'economically rational') than it really is. It suggests that if a passenger cannot fly from Heathrow they will consider flying from another airport or via another hub. However, in practice, this may not always be the case. For instance, some passengers – e.g. the elderly or

passengers of reduced mobility – may only travel if there is a direct connection available regardless of one-stop options. So if expansion leads to more connections and greater frequencies, we would expect to see additional travel where the benefits may be significantly in excess of changes in consumer surplus or shadow costs or GTC. However, these benefits were not included in the AC's analysis.

- Extra business travel: The AC set out the logic of how expansion would lead to more business travel and how this in turn would lead to wider economic benefits. This is set out below.

Figure 14 How business travel leads to wider economic benefits



Source: *https://assets.publishing.service.gov.uk/media/5a7f718740f0b6230268f872/economy-wider-economic-impacts-assessment.pdf*

While aviation plays a key role in helping to facilitate trade and investment, traditional macroeconomic metrics, including GDP, tend to take a static short-run view, and focus on the 'balance of payments' – i.e. exports minus imports – where in effect exports are 'good' and imports are 'bad'. However, trade and investment – whether it is imports or exports – also benefit economies through longer-term spillover effects. For instance, inward investment can transfer skills and knowledge. Outward investment gives access to new markets, ideas, and talents, which can boost innovation. Imports can enable cheaper inputs helping businesses to compete more

aggressively. Increased activity can also lead to more 'agglomeration'[25]. And all of these benefits ultimately increase productivity – which is key to growth.[26] The Green Book notes "productivity effects should be included in the calculation of UK costs and benefits where they can be objectively demonstrated. Productivity effects may arise from movement to more or less productive jobs, changes in the structure of the economy, benefits from dynamic clustering or agglomeration…, private investment, product market competition or the generation and flow of ideas."

The AC estimated potential benefits up to £11.5 billion, in NPV terms, over the appraisal period. However, it did not include FDI (investment) in its analysis. This was partly due to data issues (e.g. FDI tends to be very lumpy and is often intertwined with trade). But it noted that the same logic would also apply to FDI and "perhaps to a larger extent". It noted that its approach was "likely to be an underestimate". The AC also excluded air cargo from the analysis due to data issues. Taken altogether, this therefore understates the benefits of extra business travel.

While productivity will always be an important metric for policymakers it is worth noting that the UK finds itself with a 'productivity puzzle' – as highlighted by the likes of the Bank of England, the ONS, the OBR, the IFS, and others.[27] The productivity puzzle is based on the observation that UK labour productivity grew at a rate of only 0.6% per annum over the period 2009-2023, compared to 2.2% per annum over the period 1971 to 2007.[28] And this is especially 'puzzling' as other comparable countries, including the US, Germany, and France have not seen such drastic reductions in productivity growth, suggesting that this is a UK-specific problem. As such, the links between Heathrow expansion and productivity growth are particularly relevant.

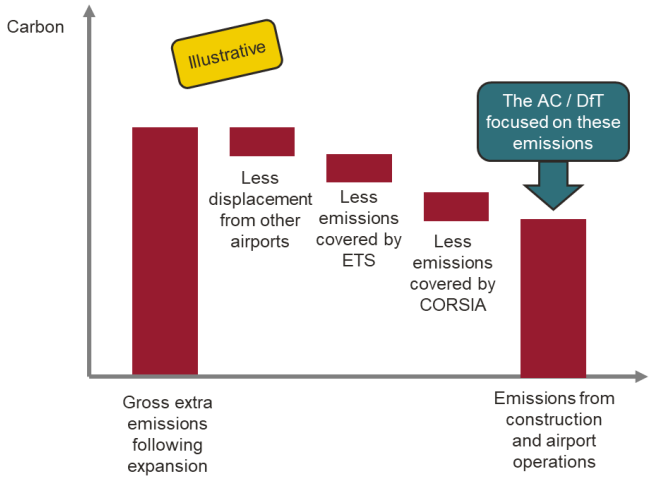
25 Agglomeration refers to efficiencies that occur when businesses cluster in the same area. For instance, clusters lead to greater knowledge sharing, lower transport and transaction costs, and labour pooling.

26 Economies can grow by increasing the size of their workforce (e.g. through immigration), or by consuming more of their natural resources, or by simply getting more out of the resources that they already have – e.g. making their workforce more productive. "Productivity isn't everything, but, in the long run, it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker." Paul Krugman, Professor of Economics and International Affairs Emeritus at Princeton University and a columnist for The New York Times

27 For instance, see: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/labourproductivity/articles/whatistheproductivitypuzzle/2015-07-07

28 https://post.parliament.uk/economic-growth-and-productivity/

- Environmental costs: The AC included carbon, noise and air quality impacts in the CBA. However, for carbon, it is important to note that the AC's analysis only captured carbon related to the airport construction phase and from airport operations. It did not include the carbon emissions from extra flights at Heathrow. This is because it assumed that any extra emissions would not be *additional* at the UK level. This is because intra-EEA flights are covered by the ETS[29] which caps total emissions. This means that an airline emitting more carbon at Heathrow would need to buy permits from other companies included in ETS – i.e. essentially paying other companies in the UK to reduce their emissions on the airline's behalf. And it was assumed that extra-EEA flights would be covered by CORSIA, where, similarly, airlines need to offset any extra emissions above a predefined baseline.[30] While this logic is true for intra-EEA flight which are covered by ETS, we note that CORSIA has not yet been fully rolled out. Progress has been very slow and it is widely considered as being very unambitious. It is expected to be mandatory for all ICAO states from 2027, meaning that by the time expansion at Heathrow comes online any extra emissions from extra-EEA flights at Heathrow will not be additional. However, it remains to be seen whether CORSIA achieves its stated objectives. Meanwhile, to help address this issue of long haul flights, the UK government is pursuing other policy options, such as potentially introducing a Carbon Border Adjustment Mechanism (CBAM).[31]



Also, the AC did not consider the impact of non-carbon gases on the environment, where the science is still evolving (albeit it did consider the impact of poorer air quality on local communities). In principle, all environmental impacts need to be included

29 EU ETS at the time of the AC report, now UK ETS. The UK Emissions Trading Scheme (UK ETS) is a carbon cap and trade scheme. ETS places a cap on total emissions on the companies / sectors included in the scheme (including airlines) and the cap reduces over time. To comply with ETS, companies must hand over enough permits to cover their emissions in a given year. They therefore face a choice of reducing their own emissions or buy extra permits from other companies that are better able to reduce emissions. It follows that some companies and sectors can emit more carbon over time whilst total emissions covered by ETS continue to fall.

30 CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) is a global scheme by ICAO that applies to international flights (in the context of the UK, this applies to long haul flight / flights outside the European Economic Area). It requires airlines to offset emissions above 2020 levels by funding carbon reduction projects, such as renewable energy.

31 https://www.gov.uk/government/consultations/addressing-carbon-leakage-risk-to-support-decarbonisation/outcome/factsheet-uk-carbon-border-adjustment-mechanism

and appropriately costed in the analysis. This therefore understates the environmental costs of expansion.

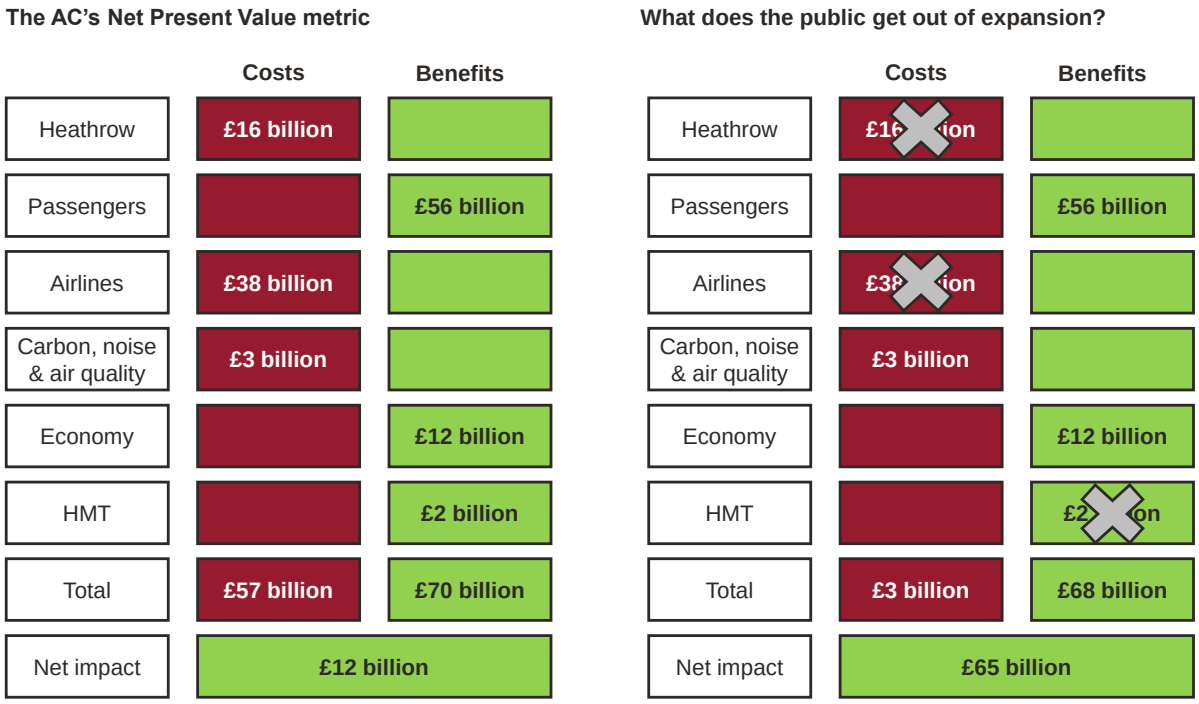
In summary, the AC's CBA represents a substantial piece of analysis. As referred to above, our main comments are as follows:

- Many of the key benefits of expansion are not actually included in the analysis. For instance, the analysis did not seek to estimate the wellbeing benefits associated with the extra leisure and VFR demand. And while ticket price savings are included in the analysis, they are effectively offset, at least in part, by the fact that lost airline profits are also included. Similarly, the wider economic benefits of the extra air travel were only partially included because the AC only looked at trade impacts, but excluded FDI as well as cargo.

- What is the appropriate scope of the CBA? We agree with the AC that it is worth considering a range of different appraisal metrics. Under the AC's broadest 'net present value' metric, the net benefits were around £12 billion over the 60 year appraisal period. However, having established a positive business case, using that broader metric, it is then worth exploring the results from different angles. For instance, if we consider what the general public gets out of the privately funded expansion (in line with the AC's 'Net Public Value' metric) we see a significantly more positive business case, with net benefits of around £65 billion over the 60 year appraisal period.[32]

[32] This involves: (i) removing construction costs, as these are funded by Heathrow, a privately-owned business with foreign shareholders, and as such this is not competing for public funds; (ii) removing airline lost profits as airlines are essentially earning 'abnormal' profits under the status quo, due to the congestion premium / shadow costs at Heathrow, and many of these airlines are not UK-based businesses, with profits taxed in other jurisdictions; and (iii) there is also a case for removing higher tax revenues (e.g. from APD) for HMT because this is a transfer from consumers. Removing taxes from the AC's CBA is therefore more conservative as it lowers the benefit side of the business case.

Figure 15 Adapting the AC's analysis: What does the public get out of expansion?



Source: Frontier analysis based on the AC's results. Numbers may not add up exactly due to rounding. Estimates relate to the AC's Carbon Traded scenario. Estimates are expressed in NPV terms over a 60 year appraisal period.

Going one step further, having established a net positive business case, the CBA could then also consider the impact on different stakeholders, to better understand who the relative winners and losers are, and whether we are comfortable with the outcomes. A high level overview is shown below.

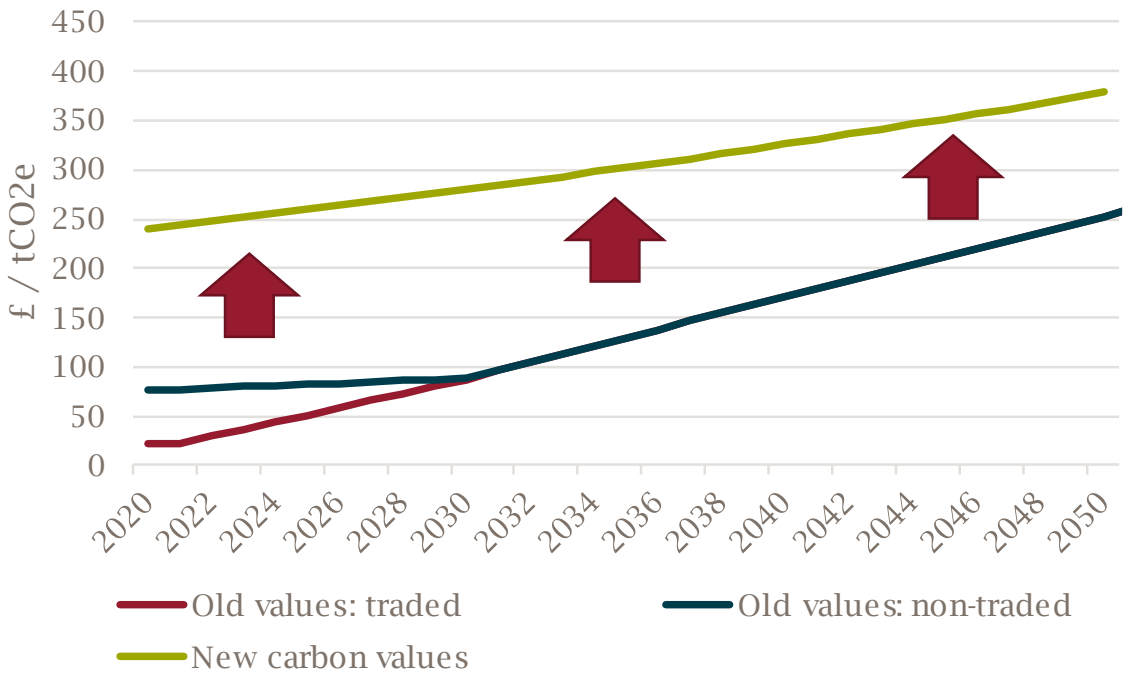
Figure 16 Design a flexible and transparent CBA

	Costs	Benefits	Expected net position
Heathrow	Construction costs; Higher operating costs	Additional revenue; Efficiency cost savings	Small positive (given Heathrow is regulated)
Passengers		Lower fares for existing passengers; More passengers; More destinations, improved frequency	Very positive
Airlines	Loss of congestion premium (incumbents); Higher operating costs for extra flights	Additional profit (new entrants)	Very negative (incumbents) Small positive (new entrants)
Cargo	Higher operating costs for extra flights	New markets; Improved capacity	Small positive
Carbon	Carbon emissions (but not all incremental)	Scale benefits? Renovation?	Negative
Environment (other)	Non carbon emissions (but not all incremental)	Scale benefits? Renovation?	Very negative
Wider economy		Trade and investment; Agglomeration	Very positive
Airspace	Congestion		Negative
Surface access	Surface access costs	Improved infrastructure; Extra capacity	Small positive
Local community	Noise; Air quality; Road congestion; Construction	More jobs / higher paid jobs; Improved infrastructure	Mixed (winners and losers)
UK regions		Improved connectivity; Economic benefits spillover	Positive
HMT	Any public funding?	More APD; Second order tax impacts	Positive
Other airports	Lower demand (Displacement)	New domestic connections	Mixed (winners and losers)

Source: Frontier analysis.

- More focus is needed on environmental costs: The AC's analysis only included carbon emissions (as well as air quality and noise), but did not consider other non-carbon gases. In principle, all environmental costs should be included and appropriately costed in the analysis. Also, since the AC's Final Report was published the UK government has since updated and increased its 'carbon values' i.e. the value that the government places on carbon emissions when carrying out CBA.

Figure 17 The UK government updated and increased its carbon values



Source: Frontier analysis based on the DESNZ carbon values.

The updated carbon values are now around 2-3 times greater than the older values, on average.[33] The updated CBA would need to reflect these higher carbon costs. The AC also only excluded carbon emissions from extra flights as these were assumed to not be *additional*. We agree this is a reasonable assumption for intra-EEA flight, which are covered by UK and EU ETS. However, for extra-EEA flights, it remains to be seen whether CORSIA is successful and achieves its stated objectives. While CORSIA should be fully operational in 2027, if this is not the case, then extra emissions from extra-EEA flights would need to be included and appropriately costed in the analysis.

2.2.2 The AC's CGE modelling

In addition to the more bottom up approach described above, the AC also commissioned Computable General Equilibrium (CGE) modelling of the different expansion options.[34]

CGE modelling captures that the economy is made up of multiple interconnected sectors. Given that sectors buy and sell goods and services with each other, an expansion in one sector (e.g. expansion at Heathrow) may stimulate other sectors. But at the same time,

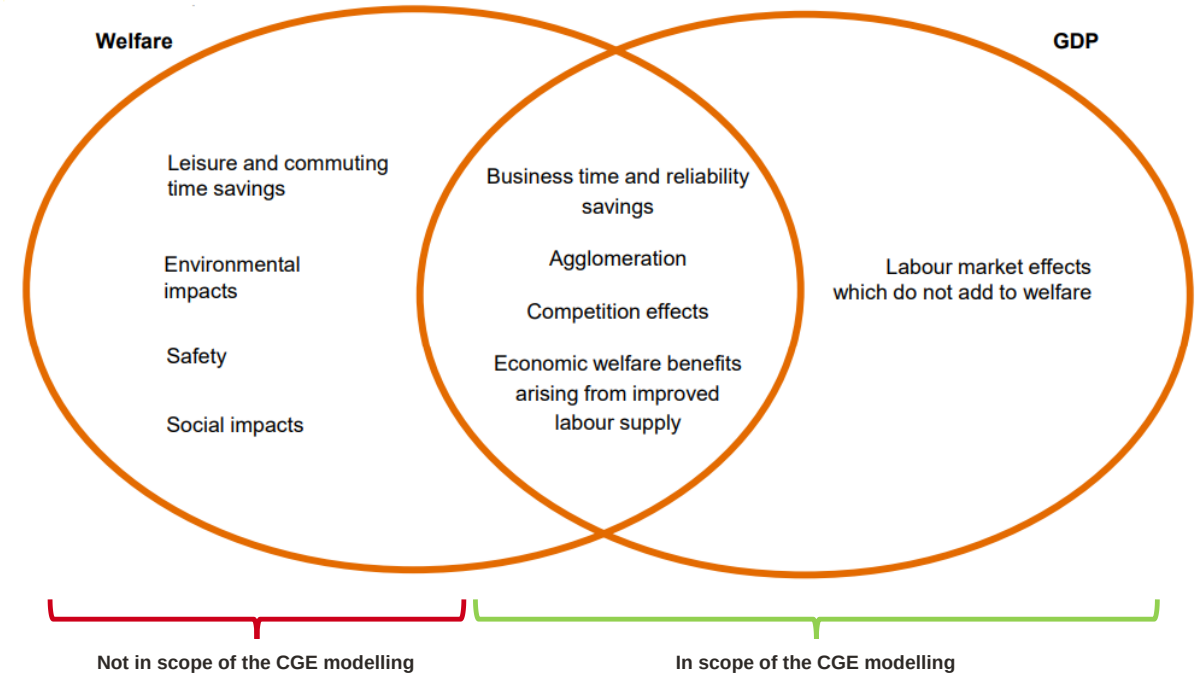
[33] The carbon values increased to account for more ambitious Net Zero targets – e.g. 2016 Paris Agreement. BEIS will update its carbon values every 5 years - in line with carbon budgets - to ensure carbon values stay up to date but also are not changed too frequently.

[34] https://assets.publishing.service.gov.uk/media/5a7eb64c40f0b6230268b0e2/2-economy--wider-impacts-assessment.pdf

expansion requires greater use of factors of production and finance, which are ultimately finite, leaving fewer resources for other sectors, driving up cost and prices across the economy as a whole, and potentially leading to contractions in other sectors. (See Box 2 for more details on 'crowding in' and 'crowding out'.) CGE modelling therefore seeks to model how an expansion in one sector (e.g. in this case expansion at Heathrow) ripples through the economy which then ultimately settles in a new equilibrium.

Importantly, CGE modelling focuses only on economic / market effects (e.g. household consumption, trade, investment, exchange rates, and GDP). It does not model non-economic effects such as environmental or social impacts. This is highlighted below.

Figure 18 CGE modelling focuses on economic effects



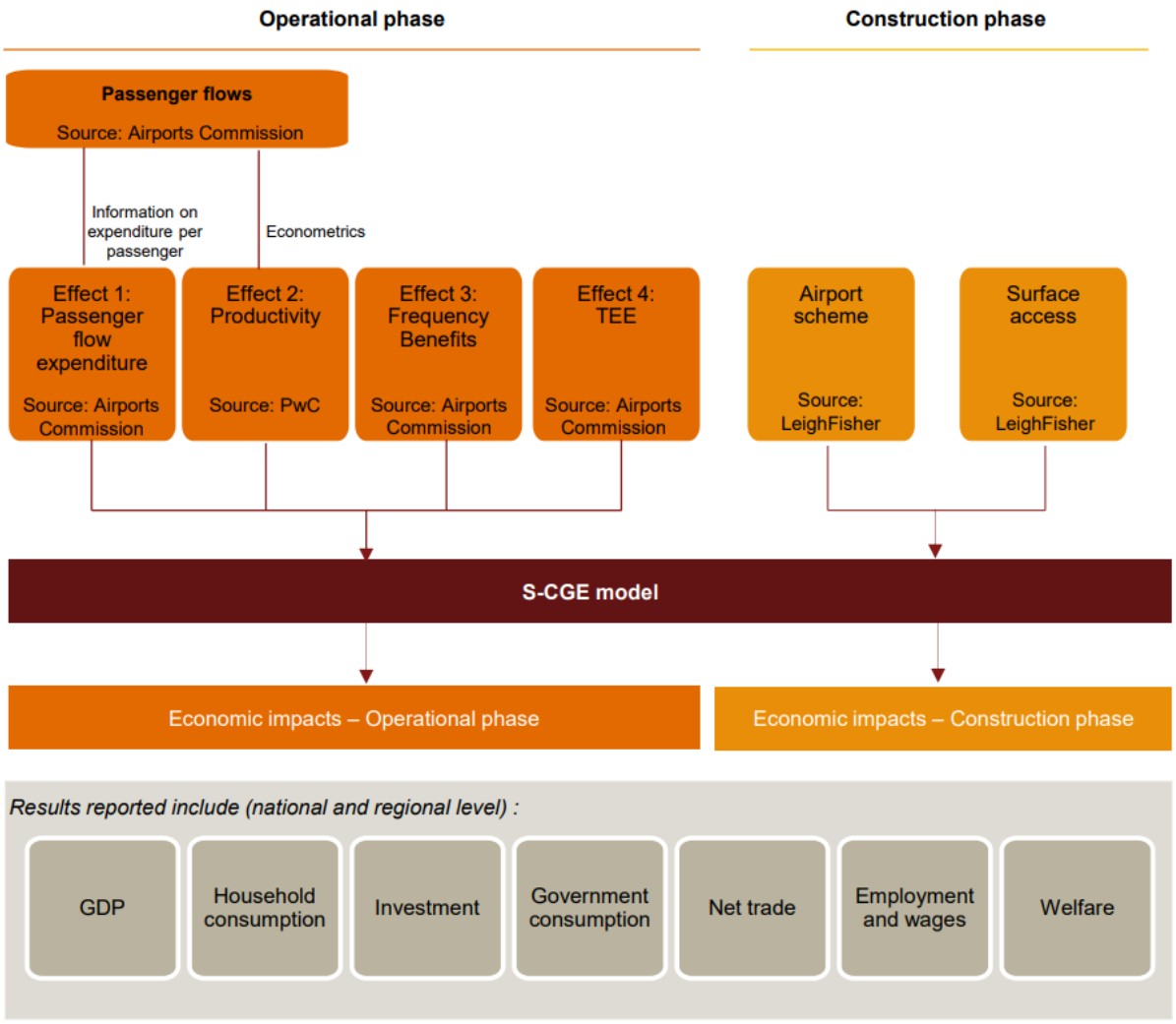
Source: Frontier – adapted from the AC's CGE analysis

As such, while there is some overlap between the CGE modelling and the AC's bottom up approach above – for instance ticket prices savings essentially appear in both – they also need to be viewed alongside each other to come to a more complete picture. This was noted in the CGE analysis: "The AC have conducted or commissioned separate studies on other impacts, such as direct user benefits, local economic impacts, environmental impacts and safety. This report [the CGE modelling] is therefore intended to be one input into a broader assessment, and its findings should be considered alongside the other studies that have been undertaken."[35]

[35] https://assets.publishing.service.gov.uk/media/5a7eb64c40f0b6230268b0e2/2-economy--wider-impacts-assessment.pdf

The diagram below provides a high level overview of the modelling approach.

Figure 19 Overview of AC CGE modelling approach



Source: https://assets.publishing.service.gov.uk/media/5a7eb64c40f0b6230268b0e2/2-economy--wider-impacts-assessment.pdf

The modelling covered the period 2016-2064. For both Heathrow expansion options considered (the HAL-sponsored northwest runway ('NWR') option, and the alternative Heathrow extended northern runway ('ENR') option) the construction phase was assumed to last from 2019 to 2026, with the operational phase beginning immediately thereafter. The modelling results were presented across five different future scenarios (e.g. a scenario with higher than expected growth and a scenario with lower than expected growth), with net changes to GDP as the headline measure.

The economic impacts of the expansion scenarios over the modelling time horizon were the sum of the effects of the construction phase and operational phase, with the latter making up most of the overall impact. The impacts reflected:

- Changes to passenger flows and effects on spending. Changes in passenger flows lead to changes in spending patterns in the UK and abroad. Spending by inbound passengers in the UK increases GDP, while spending by outbound passengers abroad reduces GDP.
- Changes to productivity resulting from increased connectivity to businesses. As discussed earlier, the general logic here is that expansion leads to more business travel which facilitates more trade, and greater openness (imports plus exports) boosts productivity and therefore GDP.
- 'Frequency benefits' which capture benefits to business travellers specifically from increased connectivity.
- 'Transport economic efficiency effects' (TEE) which capture the increase in consumer surplus due to the lower ticket prices brought about by expansion (i.e. the ticket price savings described above), netted off against a loss of producer surplus from lower margins for airlines.

The table below summarises the results. The range reflects that the AC considered a range of different future growth scenarios – ranging from a low growth scenario ("Relative decline of Europe") to a high growth scenario ("Global growth").

Table 1 Summary of AC CGE modelling

Expansion scenario	Change in real GDP by 2064 relative to the baseline (%)	NPV of real GDP increases over the modelling period (£ billions)
Northwest runway (NWR) scenario	0.5 – 1.2	95.2 – 184.5
Extended northern runway (ENR) scenario	0.5 – 1.2	85.8 – 187.4

Source: AC CGE modelling
Note: The modelling period covered 2016-2064

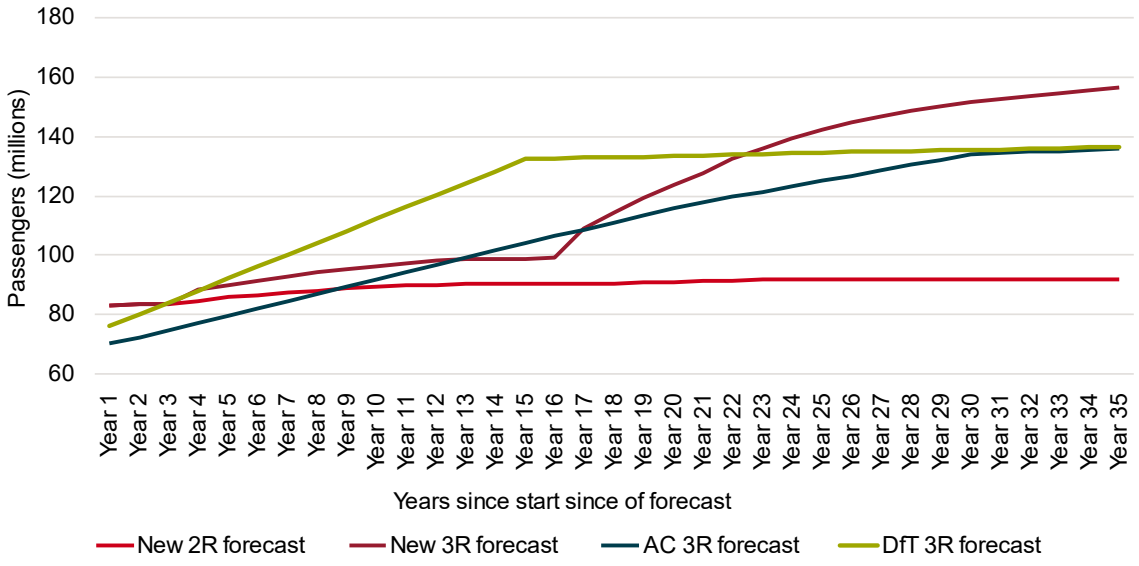
Both Heathrow expansion options were estimated to deliver significant net benefits. As discussed, this analysis did not include non-economic welfare impacts, such as wellbeing benefits for leisure and VFR demand, or negative impacts on the environment, noise and air quality. However, if we were to include the AC's estimates of the negative impacts on the environment, noise and air quality (around £3 billion over the modelling period) we still see a significant net benefit.

2.3 Overview of the DfT's analysis

The DfT published updated aviation demand forecasts for the UK in 2017[36], with the updated forecasts showing higher figures for the UK as a whole. Given that its previous passenger forecasts had been a key input into the AC analysis, the DfT decided to also update the AC's CBA at the same time. (We understand it did not publish updated CGE modelling results.[37])

In the chart below we compare the DfT's forecasts with the AC's forecast, as well as the newer forecasts currently being considered by Heathrow. The DfT's forecast envisaged demand ramping up even faster than the AC's. Given Heathrow's newer forecasts now envisage expansion happening at a much later date, and because the ramp up in demand is now slower, all other things being equal, we would expect the benefits associated with Heathrow's current expansion options to be lower than the benefits estimated by the DfT.

Figure 20 Comparison of DfT, AC and Heathrow passenger forecasts



Source: *Frontier Economics analysis of AC, DfT and Heathrow forecast*

Note: *AC and DfT forecasts are provided for set yearly intervals (i.e. 2030, 2040, 2050), as such we have interpolated the passenger numbers for the years in between.*

A comparison of the DfT's analysis to the AC's analysis is shown below. At first glance, the DfT's CBA suggested a weaker – but still positive – business case, with 'net present value'

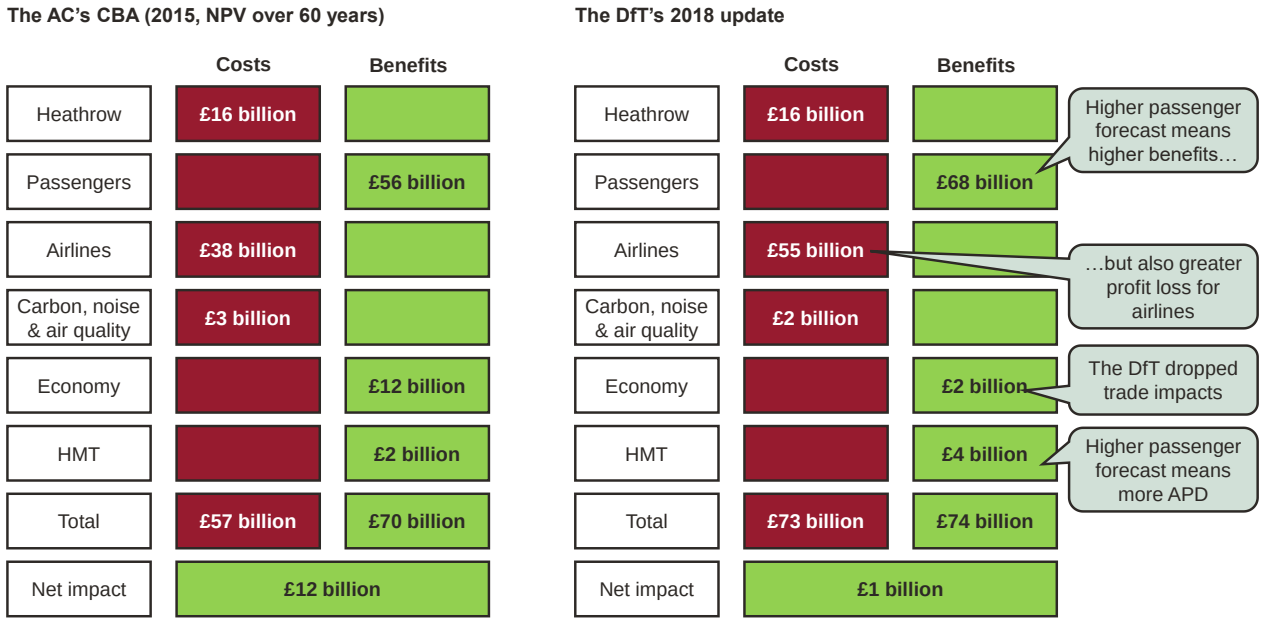
36 https://www.gov.uk/government/publications/uk-aviation-forecasts-2017

37 The DfT noted: *"it is highly challenging to produce a single central estimate of the GDP impact of airport expansion using the S-CGE approach with the evidence currently available. The existence of the relationships within the modelling, however, is accepted (such as an increase in airport capacity leading to greater levels of productivity)."* https://assets.publishing.service.gov.uk/media/5a80bfcee5274a2e87dbb996/further-review-and-sensitivities-report-airport-capacity-in-the-south-east.pdf

(the broadest appraisal metric) decreasing from around +£12 billion in the AC's 2015 analysis to around only +£1 billion in the DfT's analysis. At a high level, the main changes were:

- Higher volumes: Because the updated passenger forecasts were greater, the estimated benefits were also greater. However, at the same time, this also implied greater lost profits for airlines.
- Trade and agglomeration: However, the key driver of the difference is that the DfT decided to remove trade and agglomeration benefits from the analysis. This alone reduced the benefits by around £10 billion. We discuss this point in more detail below, and set out why we believe this decision was extremely conservative. Or viewed in a more positive light, the business case was still positive even though wider economic benefits were largely excluded from the analysis.

Figure 21 The DfT's updated 2018 analysis



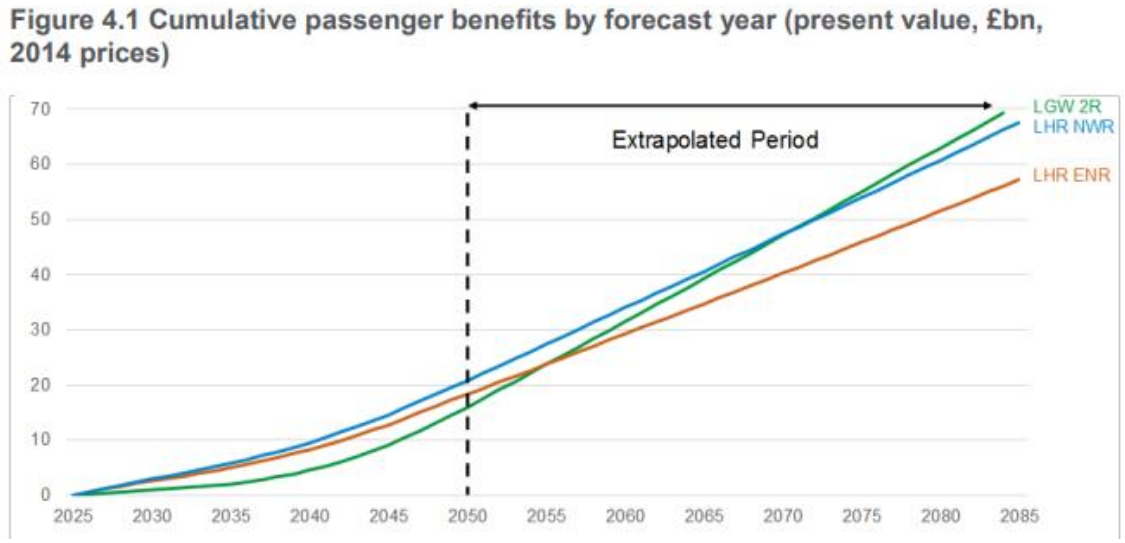
Source: *https://assets.publishing.service.gov.uk/media/5b0af93d40f0b673fc7952ed/addendum-to-the-updated-appraisal-report-airport-capacity-in-the-south-east.pdf.*

Note: This is based on the AC's and the DfT's 'carbon traded' scenario. Figures may not add up exactly due to rounding.

The DfT's extrapolation approach

Before discussing the details of the DfT's CBA, we first highlight an issue with the main results. The DfT's update suggested that expansion at Gatwick (shown as the green 'LGW 2R' line in the chart below) would eventually deliver greater cumulative passenger benefits (in NPV terms out to 2085) than expansion at Heathrow (shown as the blue 'LHR NWR' (northwest runway) line below). (However, the Gatwick option only overtook the Heathrow option in the 2070s.) This result seemingly reversed the result from the AC's earlier analysis, and understandably caused some confusion, especially since the ANPS still supported expansion at Heathrow.

Figure 22 The DfT's extrapolation



Source: *DfT*

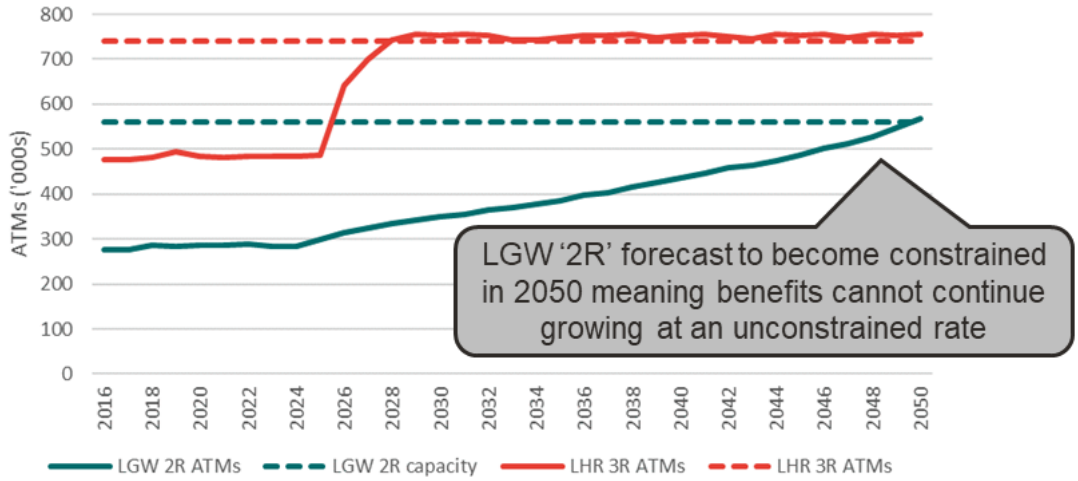
Note: *https://assets.publishing.service.gov.uk/media/5b0af93d40f0b673fc7952ed/addendum-to-the-updated-appraisal-report-airport-capacity-in-the-south-east.pdf*

However, reviewing the DfT's approach, there appears to be an issue with the extrapolation. The DfT explicitly modelled the benefits out to 2050, which was the end point in its modelling analysis, and it then applied an extrapolation out to 2085 so that its analysis would cover a full 60 year appraisal period. But in doing so, it appears the DfT did not appropriately consider capacity constraints:

- 'LHR NWR' was assumed to be full by around 2030 (see below) and therefore the benefits between 2030-2050 were growing only at a constrained rate. To forecast the benefits beyond 2050, the DfT appears to have then extrapolated the benefits using this constrained growth rate (which we believe is reasonable).
- 'LGW 2R' was assumed to become full only in 2050 (see below), meaning that prior to 2050 the benefits were still growing at an unconstrained rate. To forecast the benefits beyond 2050, the DfT appears to have extrapolated the benefits using this *unconstrained* growth rate. However, this is not credible as it fails to take into account that LGW 2R was assumed to already be full in 2050, meaning that benefits beyond 2050 would start to grow only at a *constrained* rate, like at Heathrow.

In other words, the DfT's extrapolation appears to assume that LGW 2R would continue to grow in perpetuity even though it had already reached full capacity.

Figure 23 Heathrow and Gatwick volumes (ATMs) and capacity



Source: Frontier analysis based on DfT data
Note: https://assets.publishing.service.gov.uk/media/5e8dec2786650c18c9666633/uk-aviation-forecasts-2017.pdf

If the DfT were to update its analysis, then if nothing else, we recommend that this approach is reviewed and refined.

The DfT dropped trade and agglomeration impacts

The DfT largely adopted the AC's approach, but it made some changes. Having reviewed the AC's approach it decided to remove trade and agglomeration benefits from the CBA. This is shown below. This had the effect of reducing total benefits in the DfT's CBA by around £10 billion.

Figure 24 The DfT dropped trade and agglomeration benefits from the CBA

The AC's original analysis

Table 5: Assessment of Need results, present value

Assessment of Need (£millions)	Imports	Exports	Net agglomeration	Tax Wedge	Business Output Benefits	Total
GAL	1,108	5,193	580	148	1,108	8,136
HAL	1,269	6,070	1,666	1,102	1,360	11,466
HUB	1,089	5,212	1,504	1,015	1,168	9,988

✗ ✗ ✗ ✓ ✓

The DfT's update

		Net Agglomeration	Business Output	Tax Wedge	Total
LGW Second Runway	FRSR (AC Forecasts)	0.3 to 1.6	1.1	N/A	1.4 to 2.7
	DfT17	N/A	1.2	-1.1 to 0.1	0.1 to 1.3
LHR Extended Northern Runway	FRSR (AC Forecasts)	0.5 to 2.1	1.2	N/A	1.7 to 3.3
	DfT17	N/A	1.1	0.5 to 1.7	1.6 to 2.7
LHR Northwest Runway	FRSR (AC Forecasts)	0.7 to 2.5	1.4	N/A	2.0 to 3.9
	DfT17	N/A	1.2	0.5 to 1.9	1.8 to 3.1

Source: *https://assets.publishing.service.gov.uk/media/5a7f718740f0b6230268f872/economy-wider-economic-impacts-assessment.pdf*

Note: 'Business output benefits': With airport expansion, there is a fall in the cost of production due to lower transport costs. This allows the cost per unit to fall and firms are able to increase production and reduce the price they offer to consumers while still keeping their profit margins.

The DfT estimated that trade benefits could be as high as £130 billion over the 60 year appraisal period[38], which would have been the single biggest input in the CBA, dwarfing ticket price savings of around £68 billion and construction costs of £16 billion. However, it noted that it was difficult to produce robust estimates – and indeed there is no consensus on how these benefits should be estimated, and the science continues to evolve. It noted: "while the department fully recognises the existence of wider economic impacts, it also recognises that the exact magnitude remains uncertain." But ultimately, it decided to exclude trade benefits from the analysis "due to the risk of double counting impacts with business passenger benefits included in the direct economic impacts" – although it did give details on how exactly this double counting would arise, and it is not clear to us that there is double counting:

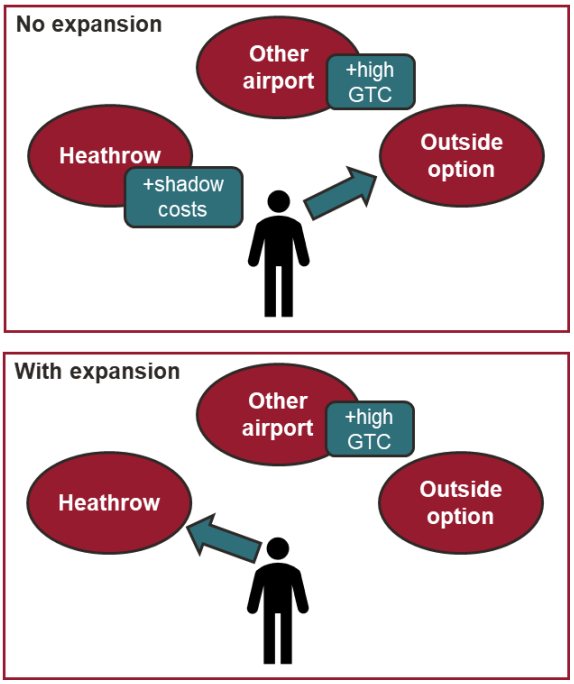
- First, the main component of 'business passenger benefits' is ticket price savings. It is important to note that there are effectively two types of business passengers in the analysis and they benefit from different things:

38 https://assets.publishing.service.gov.uk/media/5a8245a9ed915d74e6236b38/updated-appraisal-report-airport-capacity-in-the-south-east.pdf

- *existing* business travel that would have happened anyway even under a 2R scenario. These businesses benefit from the ticket price savings, which is a static benefit; and
- *new* business travel that only happens under the expansion scenario. This group is the new business demand that ultimately drives increased trade, and associated productivity benefits, which is positive *spillover* benefit. This is more of a dynamic benefit.

Both of these benefits happen in parallel. Therefore, it is not clear that there is double counting.

- Perhaps the issue arises because when considering whether to fly, businesses weigh up the expected net benefits (e.g. the likelihood of winning extra business minus travel costs), and they compare this to outside options. When faced with high ticket prices, if they choose not to fly, this may suggest that these opportunities were less valuable than the outside options. Therefore, if a reduction in ticket prices were to lead to more business travel, this may simply result in those outside options being displaced by new opportunities that only deliver marginally greater value.



  If this is the concern, then it is important to remember, as discussed previously and as noted in the Green Book, that the contribution that trade makes to GDP is not just the short-run 'static' impact (i.e. exports minus imports) but the longer-term productivity benefits. More trade as a result of expansion will lead to productivity gains that go beyond the specific business in question – i.e. they are a long-term *externality / spillover* rather than a short-term *private* benefit.

- There are also real world considerations. Some business travel may only materialise if there is a direct connection, irrespective of ticket prices. Therefore, expansion, which would lead to more connections, would drive brand new business travel. Similarly, businesses may be risk averse when it comes to certain types of business travel – e.g. conferences, where the benefits may feel less tangible and more speculative. Lower ticket prices and direct connections would help, at least in part, reduce these barriers.

The DfT also decided to remove agglomeration benefits from the analysis. It noted that there were two agglomeration effects following expansion: (i) increased business clusters around

the expanded airport leading to *positive* spillovers; and (ii) increased congestion around the expanded airport from job relocation leading to *negative* spillovers. The DfT noted that it was difficult to robustly measure these negative impacts, and so it decided to exclude agglomeration entirely. We accept that it is challenging to quantify these dynamics accurately. However, excluding them entirely from the analysis is very conservative.

This means that the DfT's wider economic impacts were essentially limited to the following impacts:

- 'Tax receipts' – i.e. workers move into more productive jobs which leads to higher tax receipts for government – which is also arguably a transfer within the economy; and
- 'Increased business output' – i.e. with expansion, there is a reduction in transport costs, which leads to a fall in production costs. This enables firms to increase production and reduce prices for consumers whilst still maintaining profit margins. However, in this scenario, productivity has not increased through any technical innovation. All that has happened is there has been a relative change in price leading to some additional output.

Both of these impacts were relatively small and do not seem to appropriately capture the key wider economic impacts of air travel. For instance, the very first line of the Executive Summary of the AC's Final report notes that: *"The position of the UK within the global aviation market is critical to its economy: it is central to ensuring increased productivity, growth and employment opportunities."* It is true that these impacts are challenging to quantify, but these benefit types are ultimately one of the main reasons for expansion in the first place. Ultimately, we find the DfT's approach of excluding trade benefits (as well as FDI, air cargo and agglomeration) to be very conservative.

Net present value versus net public value

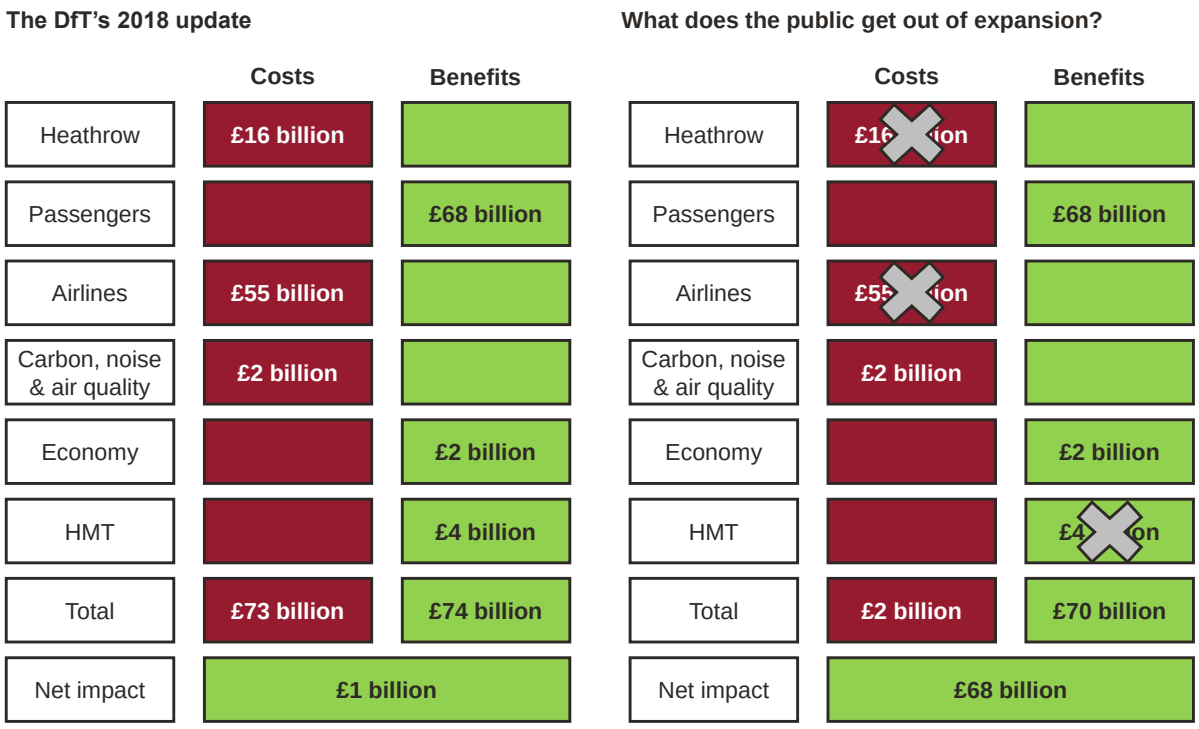
Taken altogether, this means that many of the benefits of expansion, that we might intuitively consider to be the key benefits of expansion, are not actually included in the DfT's analysis:

- More leisure and VFR travel leading to greater wellbeing → The DfT estimated the increase in consumer surplus, which is a narrow economic measure of welfare. But it did not seek to estimate the wellbeing and life satisfaction benefits from extra leisure and VFR travel, and the potential for this to lead to higher labour productivity.
- Higher trade leading to higher productivity → Air travel is an essential input for many businesses and is positively linked with greater trade, which in turn is positively linked with higher productivity. The DfT estimated that this benefit could be as high as £130 billion in NPV terms over the modelled period, but it was ultimately dropped from the analysis due to the 'double counting' discussed above, which we disagree with.
- Lower ticket prices → Depending on the appraisal metric considered, these were not (fully) included in the analysis because they also amount to a transfer – i.e. lower revenue for airlines.

So what are we left with? Analysing the DfT's approach, we are essentially left with some relatively modest benefit types: lower delays and frequency benefits for existing passengers, increased consumer surplus for extra leisure and VFR demand, 'increased business output', and higher tax revenue for government, which is also arguably a transfer. Meanwhile, construction costs and environmental costs are more easy to observe and quantify robustly. The removal of trade and agglomeration benefits means that the DfT's updated approach therefore sets a much a high bar to demonstrate a positive business case when taking the broadest 'net present value' appraisal metric. However, even with this higher bar, the DfT still found a positive net present value. And if the AC's estimate of the wider economic benefits associated with trade (around £7 billion) were reintroduced into the DfT's analysis, the benefits' side of the CBA would increase significantly – and even more significantly if the DfT's higher estimate of £130 billion was used.

While the DfT's analysis appears to suggest a weaker business case, relative to the AC's analysis, if we consider the AC's 'net *public* value' metric, and ask what the public gets out of the private investment – i.e. by excluding privately funded construction costs, lost airline profits, as well as taxes – we see that the business case increases from around £65 billion (AC estimate) to £68 billion, and as noted, this still excludes the various benefit types described above.

Figure 25 Adapting the DfT's analysis: What does the public get out of expansion?



Source: Frontier analysis based on the DfT's results. Numbers may not add up exactly due to rounding. Estimates relate to the Carbon Traded scenario. Estimates are expressed in NPV terms over a 60 year appraisal period.

3 Overview of our analysis

3.1 Introduction

In this section we provide an overview of the analysis that we have carried out and discuss our overall results.

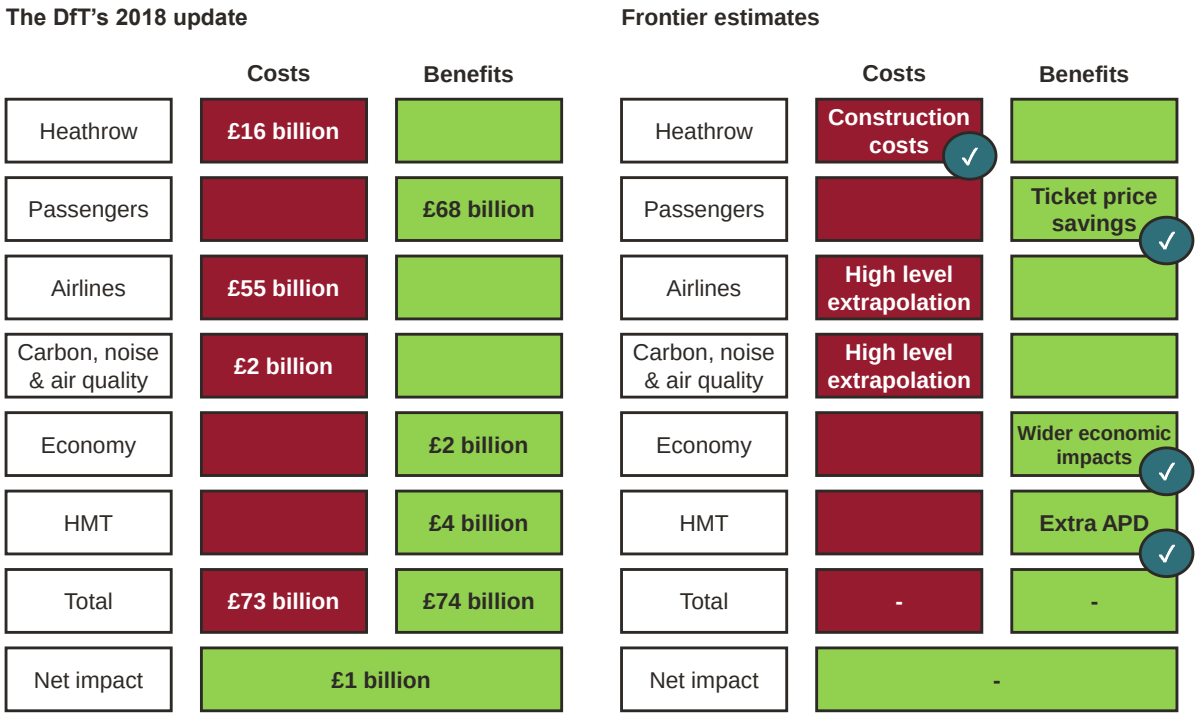
3.2 Overview of approach

Similar to the AC, our analysis is split in two main parts:

- 'Bottom up' individual impacts: We have estimated:
  - Ticket price savings;
  - Wider economic impacts; and
  - Extra government tax revenues from APD.

  We also have construction cost forecasts for the different expansion options provided to us by Heathrow. For the other impacts included in the DfT's analysis, we have taken the DfT's previous estimates and applied some high level extrapolations. Further work would be needed to improve these estimates. A high level overview is shown below.

Figure 26 What have we estimated?



- CGE modelling: We have also carried out our own CGE modelling in partnership with Centre of Policy Studies (CoPS), Victoria University Melbourne.

We discuss these points in turn.

3.3 Individual impacts

3.3.1 Ticket price savings

We have estimated the impact of the different expansion options on ticket prices at Heathrow. At a high level, our approach is as follows:

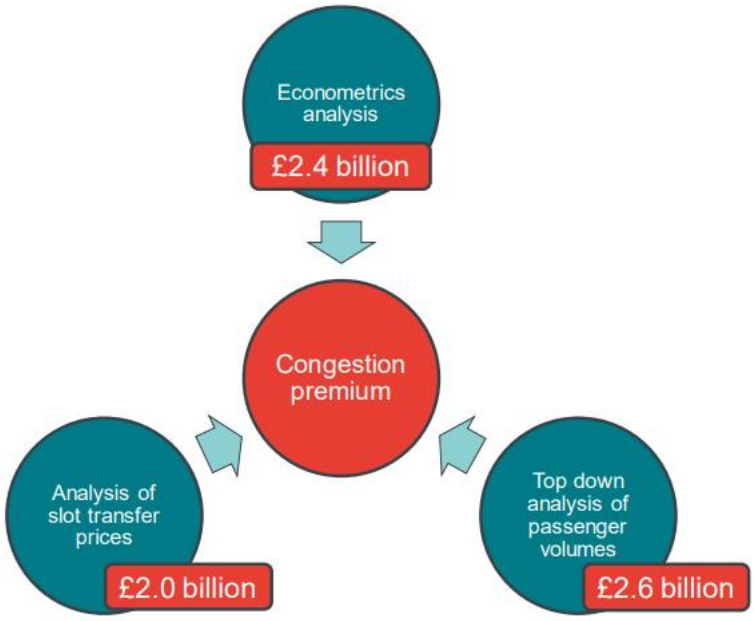
- First, we estimate the size of the congestion premium at Heathrow today;
- Second, we forecast how the congestion premium can be expected to evolve over time under the 'do nothing' scenario; and
- Third, we then consider how the extra capacity added under the different expansion options would ease congestion and lead to lower ticket prices.

We discuss these points in turn below.

The congestion premium today

We have estimated the congestion premium at Heathrow on several occasions. For instance, in a 2019 report for Heathrow[39] we estimated the premium using three separate approaches, that all pointed to broadly the same answer: that the premium at Heathrow was worth around £2-3 billion per annum in extra revenue for airlines, relative to a hypothetical unconstrained scenario.

Figure 27 We previously estimated the premium using different approaches



Source: Frontier 2019 'Estimating the congestion premium at Heathrow'

In 2019, the CAA commissioned a review of the congestion premium at Heathrow, which included a review of our evidence on the topic. Ultimately, it accepted that there was a premium at Heathrow, noting that "we consider that it is likely that some airlines are earning scarcity rents *[a congestion premium]* at Heathrow" and that assuming a premium in the range of "£0.9 billion-£2.5 billion per annum" was "conservative".[40]

For this piece of work, we have updated our econometrics analysis to extend to 2023 data on ticket prices. Our approach is largely the same as in our previous reports.[41] At a high level, we start by comparing ticket prices at Heathrow with those at a sample of other large European airports, and other London airports, over the period 2016-2023. A simple high level comparison does indeed show that there is a 'raw' premium at Heathrow – i.e. that average

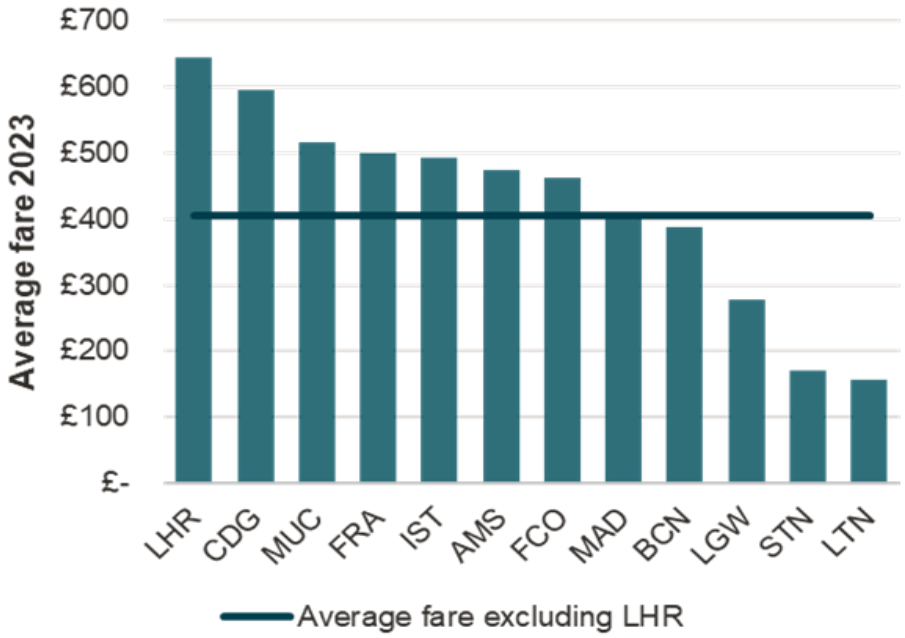
39 https://www.caa.co.uk/media/dwfgyk53/estimating-the-congestion-premium-at-heathrow.pdf

40 https://publicapps.caa.co.uk/docs/33/CAP1871%20Early%20expansion%20costs%20condoc%20v1.6.pdf

41 For further details on our approach, please see section 4 in our 2019 report: https://www.caa.co.uk/media/dwfgyk53/estimating-the-congestion-premium-at-heathrow.pdf

ticket prices at Heathrow are higher than those at the other airports in our sample, on average. For instance, the chart below compares average ticket prices for long haul flights at the different airports in our sample.

Figure 28 Average fare at LHR compared to other sample airports for long haul



Source: *Frontier analysis of IATA AirportIS data.*

Note: *LHR average fare is 59% higher than the average fare at the other airports in the sample for long haul. This is based on the average fare of single trips departing from each airport. For long haul, we use a distance threshold of greater than 2,000 miles in line with HMT's distance bands for APD.*

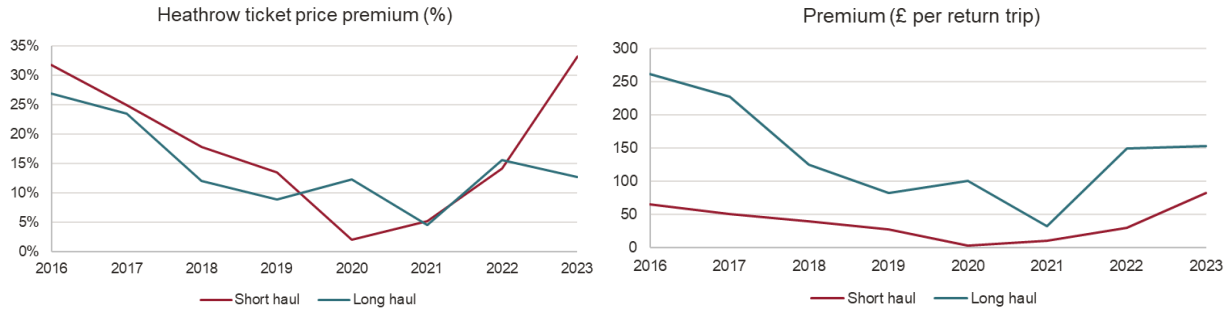
However, this in itself is not a particularly surprising result and it can be explained in part by a variety of reasonable factors. For instance, there is a relatively higher share of business passengers and business class passengers at Heathrow, and there are essentially no low cost carriers at Heathrow – both factors that can explain higher ticket prices.

We then use econometrics analysis to explain ticket prices on a given route as a function of various factors – e.g. distance, fuel costs, share of LCCs on the route, number of operators on the route, share of business class passengers on the route, etc.. By controlling for these factors, any remaining difference in price must be attributable to something else. If everything else is controlled for, we argue that any remaining difference is driven by congestion at Heathrow.[42]

[42] Under this approach, the premium is estimated as a 'residual', and is therefore exposed to the risk of omitted variable bias (OVB) – i.e. perhaps the difference is not driven by congestion, but by something else. To overcome this, we take a transparent approach, gradually adding in more and more variables into the analysis to show how the residual changes, and how ultimately it does not disappear. Also, some of the explanatory variables are themselves 'expressions' of congestion. For instance, if prices are higher because there is limited airline competition, then why is this happening? It is

The charts below summarise our results.

Figure 29 The congestion premium at Heathrow 2016-2023



Source: Frontier analysis

In our updated analysis we continue to find strong evidence of a premium, and for both short haul and long haul separately:

- Short haul – we find evidence of a premium in all years, worth up to £80 per passenger for a return trip. This equates to a premium of up to 35%.
- Long haul – we also find evidence of a premium in all years, and potentially as high as £250 per passenger for a return trip. This equates to a premium of up to 30%.
- While the premium varies year-on-year (and clearly there will be some noise due to the pandemic[43]), we find that a premium of around 20%, applied to 2024 passenger volumes[44], equates to a total premium of around £3.5 billion per annum.

because Heathrow is constrained. Therefore, there is also arguably '*included* variable bias' where part of the raw premium at Heathrow is explained away by factors that themselves are driven by congestion. Also, in previous reports we also estimated the premium using entirely different approaches (e.g. analysis of slot transfer prices), which found similar results, giving us greater confidence in our econometrics.

43 Demand collapsed during the pandemic. Therefore it is challenging to call the premium observed in 2020-2022 as a 'congestion' premium. However, the presence of a premium even in those years arises due to the same fundamental issue: the scarcity of slots at Heathrow limits the amount of capacity and competition at the airport. Or in other words, if there was scope for new entry at the airport we might have expected to see even more capacity during these years and therefore lower prices as a result. This dynamic could also be thought of as a 'slot scarcity premium'. We explain this in more detail in our report: https://www.caa.co.uk/media/mhpbazy1/46-frontier-slot-scarcity-and-ticket-prices-at-heathrow.pdf

44 Our econometrics analysis was focussed only on point-to-point passengers at Heathrow, which generally tend to represent around 50% of total passengers, with transfer passengers and 'beyond' passengers (i.e. passengers originating / terminating at Heathrow but flying on multi-stop itineraries, as opposed to direct / point-to-point) making up the remainder. This was because for transfer and beyond passengers, it is less clear that airlines at Heathrow are able to charge a premium, due to these passengers having more outside options. For instance, a passenger wishing to fly from say Edinburgh to the US may have an option to fly via Heathrow or via a number of other hubs. As such, airlines at Heathrow may be less able to charge a premium. Therefore, we conservatively apply the premium to point-to-point passengers only.

In other words, there is such excess demand at Heathrow, that airlines are able to raise ticket prices above what we would expect to see in an unconstrained market – much like what we see in other markets such as tickets for popular music events – and earn around £3.5 billion in additional revenue per annum. If there were spare capacity at Heathrow, competition between airlines would result in incumbent airlines and/or new entrants adding extra capacity on existing routes which would drive prices back down towards the competitive level.

The congestion premium in future

We have then considered how the premium can be expected to evolve in future under the 'do nothing' scenario. This is based on the following assumptions:

- Unconstrained demand: First, we need to estimate what demand would be at Heathrow today if it were not constrained. Given that we have estimated a congestion premium of around 20% at Heathrow today, we can use a 'price elasticity of demand' (PED) to back out what unconstrained demand would be. PEDs are expressed in the form: a 1% change in price leads to an x% change in demand. This captures that when prices rise, demand falls, and that when prices fall, demand rises. However, PEDs cannot be observed directly. They have to be estimated using statistical analysis that seeks to explain changes in demand over time as a function of changes in price, as well as changes in other factors, such as income. There are various publicly available studies seeking to estimate PEDs for aviation demand. The DfT published a detailed report on UK demand elasticities in 2022.[45] The report included a range of estimates for different passenger segments, covering UK passengers flying abroad v foreign passengers flying to the UK, as well as split out between business, leisure and visiting friends and relatives, and also split out across different destination regions. The results suggest a wide range of estimates, ranging from as low as -0.1[46] (suggesting very inelastic demand – meaning that prices would need to rise significantly in order to price excess demand out of the market) up to -1.1 (suggesting much lower price rises would be needed in order to price excess demand out of the market). It also estimated an 'overall' estimate of -0.9 for the UK as a whole. Using this overall estimate of -0.9, if a premium of 20% is required to price the excess demand out of the market, this implies unserved demand of around 18% today (i.e. 20% x -0.9), or in other words that rather than there being around 80 million passengers at Heathrow today, there would be around 90-95 million passengers in an unconstrained world. Clearly, the results would vary depending on the elasticity assumed. As set out below in more detail, we consider the -0.9 estimate to be conservative. This is because if we assume a higher elasticity, our estimates of the premium in future would be much lower. And as a result our estimate of the ticket price savings (which the AC and DfT found

45 https://assets.publishing.service.gov.uk/media/6235a5378fa8f540edba36f5/econometric-models-to-estimate-demand-elasticities-for-the-national-air-passenger-demand-model.pdf

46 The results also included some PED estimates of 0. However, in our view this is not credible. This would suggest that even if prices increased significantly demand would not fall at all. This finding could potentially be due to capacity constraints at Heathrow. For instance, when analysing price and demand for long haul routes, which tend to mostly be at Heathrow, we are not analysing an unconstrained market. We would be analysing data that is significantly distorted by congestion and may not be appropriate for modelling changes in demand in an unconstrained world.

to be the biggest input in their analyses) would be lower, dampening the overall business case. Also, the DfT's estimate of -0.9 may be relevant for the UK as a whole. But it may be less relevant for London, and Heathrow specifically. For instance, Heathrow has a higher proportion of business passengers compared to the rest of the UK, and the DfT finds much lower PEDs for business compared to leisure.

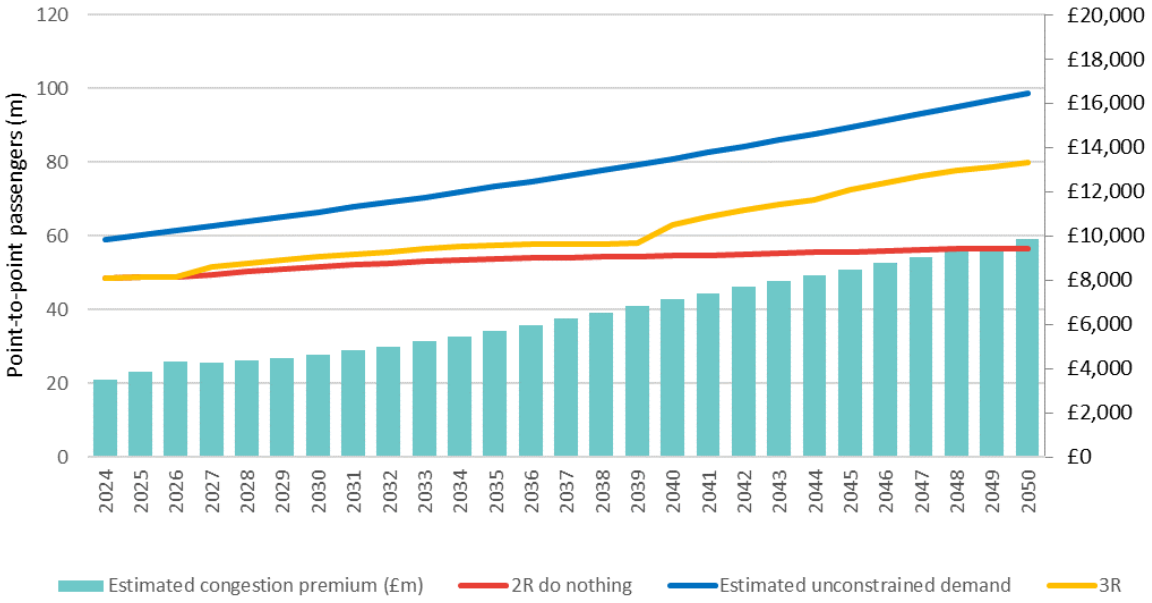
- Unconstrained demand growth: We then assume that this unconstrained demand would grow by around 2% per annum, based on the DfT's average UK growth forecast in its 2017 aviation demand forecasts. Again, this can also be considered conservative, as Heathrow is connected to more long haul destinations in faster growing economies, where incomes (and hence demand) are likely to grow at a faster rate compared to Europe, say.

- Do nothing scenario: We then consider Heathrow's 'do nothing' 2R passenger forecast which implies a much more modest constrained growth rate of less than 1% per annum – e.g. reflecting larger aircraft and higher load factors.

- Required premium: We then compare the unconstrained growth forecast to Heathrow's 'do nothing' forecast to identify the excess demand that needs to be priced out of the market through a congestion premium. We estimate the premium using the DfT's central PED estimate of -0.9. We apply this premium, in percentage terms, to ticket prices. We assume that unconstrained ticket prices remain constant in real terms over the modelling period – which is conservative as we would generally expect tighter carbon policies to lead to higher ticket prices in future.

The chart below shows our forecast of the premium over time. As the growth in unconstrained demand will outstrip the growth in available capacity we see that the premium will rise over time, rising to around £10 billion per annum by 2050. This equates to £218 billion in NPV terms over a 60 year time horizon.

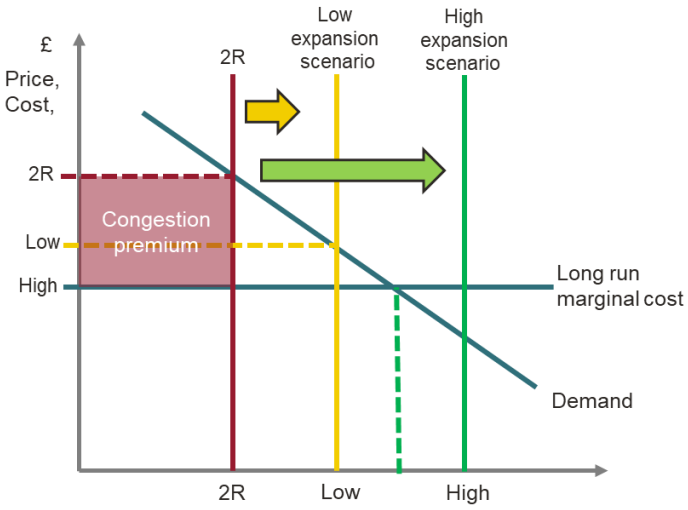
Figure 30 Forecasting the premium over time



Source: Frontier analysis

As noted above, if we were to use a lower PED estimate, our estimates would be much higher.

How will expansion ease the congestion premium?



At a high level, expansion would enable airlines to add extra capacity at Heathrow which would drive down ticket prices. For instance, if more seats were added on the LHR-JFK route, ticket prices on the route would fall. If this extra capacity is enough to serve all the unserved demand, it could entirely remove the congestion premium (e.g. see the 'high' scenario – where there is some spare capacity left over at the airport level). But if the extra capacity is only enough to serve some of the unserved demand, the premium would reduce in size, but still remain (e.g. see the 'low' scenario) because not enough capacity can be added to serve all of the unconstrained demand. However, in practice, the dynamic is more nuanced and depends on precisely how the extra capacity is used.

- New routes: Expansion will result in many new connections being added. But extra capacity on new routes may have little to no impact on the premium on existing routes – aside from the fact that some demand could potentially switch from existing routes to new routes, marginally easing the premium on existing routes. The size of this switching effect will vary from route to route. But in general, we would expect that adding a new connection to China would have little impact on the premium to the US, say.

- Short haul versus long haul: Similarly, while adding extra capacity on existing short haul routes would drive down prices on those routes, we would expect little to no impact on the premium on long haul routes, and vice versa.

- Low cost carriers: To what extent would the entry of a LCC on a particular route lower the incumbent network carrier's ticket prices on the same route? While some existing passengers may switch from the network carrier to the LCC (thereby alleviating some of the excess demand for the incumbent carrier's flights and thereby lowering the premium) others may not view this capacity as being a viable substitute, placing a limit on the benefits. Taken to the extreme, if the LCC stimulated only brand new demand and did not impact on the demand for the network carrier's flight, we would expect to see no impact on the premium.[47]

- Network carriers: Even if a network carrier were to enter a route and compete against the incumbent network carrier, there is still a degree of differentiation between network carriers. For instance, some passengers may simply prefer to fly with BA (a home nation bias, or Avios points etc.), whereas others may prefer the 'destination' network carrier.

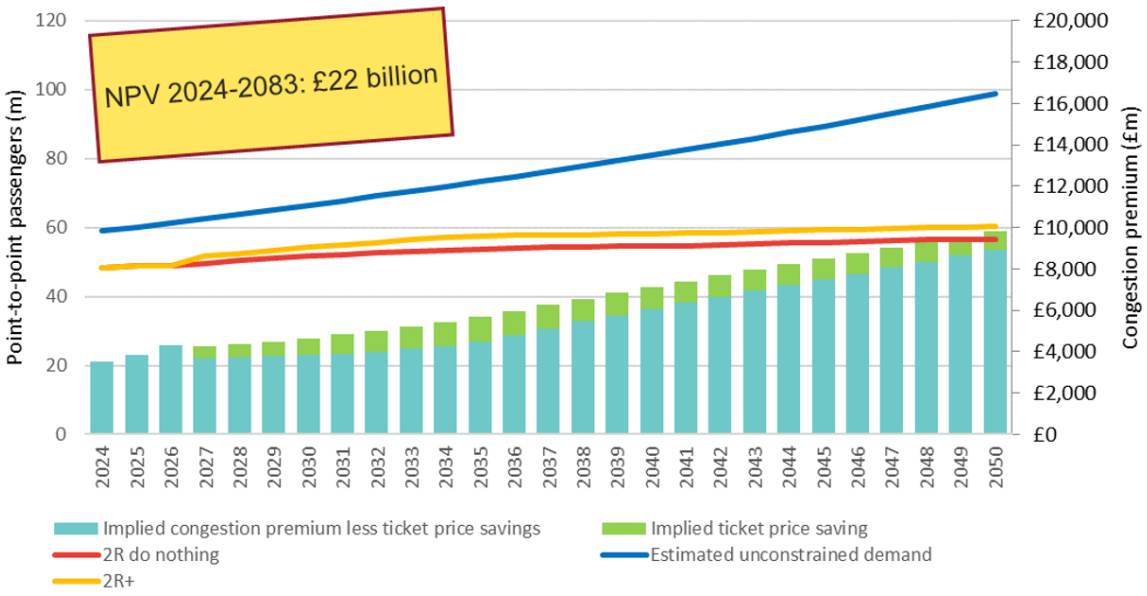
Ultimately, the size of the ticket price savings on a given route will depend on the closeness of competition / degree of substitutability between the incumbents' existing capacity and the new capacity that is added. There are also various real-world considerations. For instance, how would new slots be allocated to airlines? Existing slot allocation rules, which are based on rules adopted by the European Commission when the UK was a member of the EU, offer half of new slots to incumbents, and limit new entrant slots to such small tranches as makes it difficult to establish entry with scale to compete against incumbents. Different approaches could lead to certain airlines having more or less of the extra capacity, which could lead to different outcomes in terms of available routes, seats and prices. Technically the UK is no

[47] If an LCC were to enter a route that was previously served only by network carriers, we would expect to see three different passenger groups: (i) brand new stimulated demand that would not have flown with the network carrier – e.g. more price-sensitive demand. For this group, the benefit of expansion is the net benefit they derive from flying with the LCC minus the net benefit that they previously derived from the outside option – which is practically impossible to observe; (ii) demand that switches from the network carrier to the LCC: This group may end up paying significantly lower ticket prices (i.e. moving from the incumbent carrier, where the fare included a premium, to an LCC with a much lower prices). However strictly speaking, not all of this 'gross' saving is necessarily a benefit. This is because while the LCC may have lower ticket prices, service quality may also be lower too. The benefit for this group is therefore the net benefit (taking price and non-price factors into account) of flying with the LCC minus the net benefit of flying with the network carrier; and (iii) demand that continues to fly with the network carrier: this passenger group continues to enjoy the same service, but now ticket prices are lower as some passengers have switched to the LCC, driving down demand and ticket prices for the network carrier.

longer obliged to follow EU rules for slot allocation, but as yet no decision has been taken as to what policy the UK will adopt.

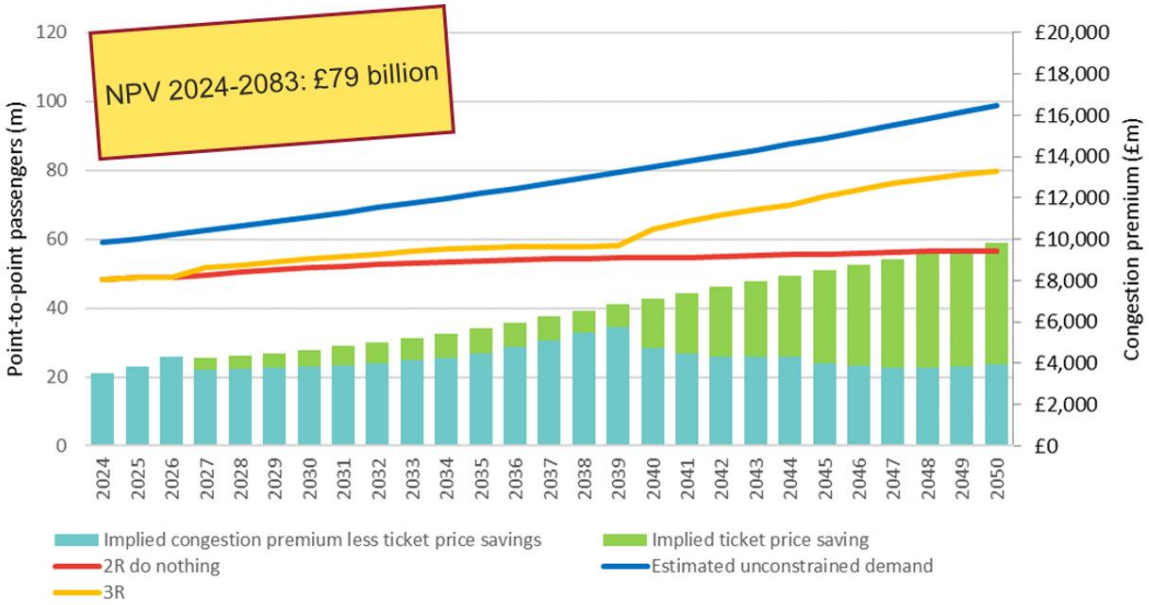
To estimate the potential ticket price savings, we take Heathrow's expansion scenario passenger forecasts and estimate how much of the unserved demand under the 'do nothing' scenario can now be served. Given the discussion above on substitutability, for simplicity, we assume that the extra capacity that is added under the expansion scenarios is viewed by existing demand as a perfect substitute to the incumbents' capacity. Using the DfT's PED estimate of -0.9, we assume that a 1% increase in capacity leads to a 1.1% decrease in price. The figures below summarise our results. Overall, we see that the premium still rises as unconstrained demand is forecast to grow faster than the increase in capacity, with excess demand continuing to grow.

Figure 31 Forecasting the ticket price savings over time – 2R+ scenario



Source: Frontier analysis.

Figure 32 Forecasting the ticket price savings over time – 3R scenario



Source: Frontier analysis.

We see that the expansion options deliver significant ticket price savings. To put these figures into perspective, these savings alone far exceed the construction costs of expansion:

- For the 2R+ scenario: We estimate savings of £22 billion versus construction costs of £6 billion, both expressed in NPV terms over a 60 year period.
- For the 3R scenario: We estimate savings of £79 billion versus construction costs of £29 billion, both expressed in NPV terms over a 60 year period.

And these results would be even higher if we used lower PED estimates, rather than the DfT's estimate of -0.9 for the UK as a whole. Comparing our results to the DfT's estimates, we note that for the 3R scenario, our estimate is greater than the DfT's estimate of £68 billion. (First, the DfT's figure was reported in 2014 prices. Expressing it in 2024 prices increases it to £89 billion.) When comparing the results:

- As noted earlier, the DfT's passenger forecast was greater than the forecasts currently being considered by Heathrow. It follows that a higher forecast leads to greater ticket price savings as more of the excess demand can be served, alleviating the premium.
- Also, in Text Box 1 earlier, we set out how the DfT's approach underestimates the congestion premium because it essentially assumes there is no congestion in the model start year (2016) and that the premium only starts building up from 2017 onwards, whereas we find clear evidence of excess demand building up at Heathrow long before 2016.

Ultimately, the congestion premium cannot be observed directly and as such there will always be a degree of uncertainty over the precise size. We and the DfT have used different approaches to estimate it. We have used multiple techniques to estimate the premium, including using econometrics analysis of ticket prices at Heathrow compared to ticket prices at other airports, whereas the DfT uses its 'NAPAM' passenger allocation model where it increases shadow costs at Heathrow in order to encourage passengers to travel to other London / UK airports instead of Heathrow. However, our estimates and the DfT's are broadly similar in magnitude, and in both our analysis and the DfT's analysis, ticket price savings are clearly the single largest impact feeding into the analysis.

3.3.2 Extra government revenue from APD

We have estimated the extra revenue that government could expect to generate from additional APD under the different expansion options. This is based on the following assumptions:

- For simplicity, we have assumed that the current structure of APD remains constant over time.[48]
- We have also assumed that the level of APD (based on the 2025 tax year) also remains constant over time. However, as a sensitivity we have included a scenario where APD rates increase by 1% per annum.
- We also need to take **displacement** into account. Expansion at Heathrow will lead to a large increase in volumes at Heathrow. However, some of this demand relates to passengers who have been 'displaced' from other airports in the UK. In the DfT's 2017 UK aviation demand forecasts it included passenger forecasts for all major UK airports. It also produced forecasts with and without Heathrow expansion. We observe that when Heathrow expands, other London airports partially contract. This is shown below.

[48] https://www.gov.uk/guidance/rates-and-allowances-for-air-passenger-duty

Air Passenger Duty (APD) is a tax charged to airlines based on the number of departing passengers that they carry. APD is not charged for transfer passengers. Therefore, our analysis is focused on O/D passengers only. APD is structured into different bands based on the destination: (i) domestic; (ii) Band A (<2,000 miles); (iii) Band B (2,000-5,500 miles); and (iv) Band C (>5,500 miles). For each of those destinations, it is also split out based on seat class, essentially making a distinction between economy class and business class passengers. However, historically, the structure has changed from time to time. We assume that this structure is held constant for the full modelling period. We focus on 2025 APD rates.

Figure 33 Heathrow displacement

DfT 2017 forecasts

Change in passengers under Heathrow expansion relative to no expansion

	2030	2040	2050
Heathrow	36.9%	38.8%	40.2%
Gatwick	-1.6%	0.3%	-0.2%
London City	-31.5%	0.2%	3.1%
Luton	-0.8%	-1.1%	-0.4%
Stansted	-28.1%	-9.7%	0.0%
London ex Heathrow total	-11.5%	-3.2%	0.0%
Birmingham	-15.4%	-21.9%	-5.4%
Bristol	-10.3%	0.1%	-2.2%
East Midlands	4.6%	-6.0%	-1.1%
Edinburgh	2.8%	5.7%	7.7%
Glasgow	-4.7%	-7.5%	-8.0%
Liverpool	8.6%	6.2%	-1.1%
Manchester	-4.7%	-3.6%	-10.2%
Newcastle	7.8%	4.2%	-4.3%
Larger regional airport total	-4.5%	-6.0%	-5.0%
Other regional	-3.4%	-17.6%	-18.4%

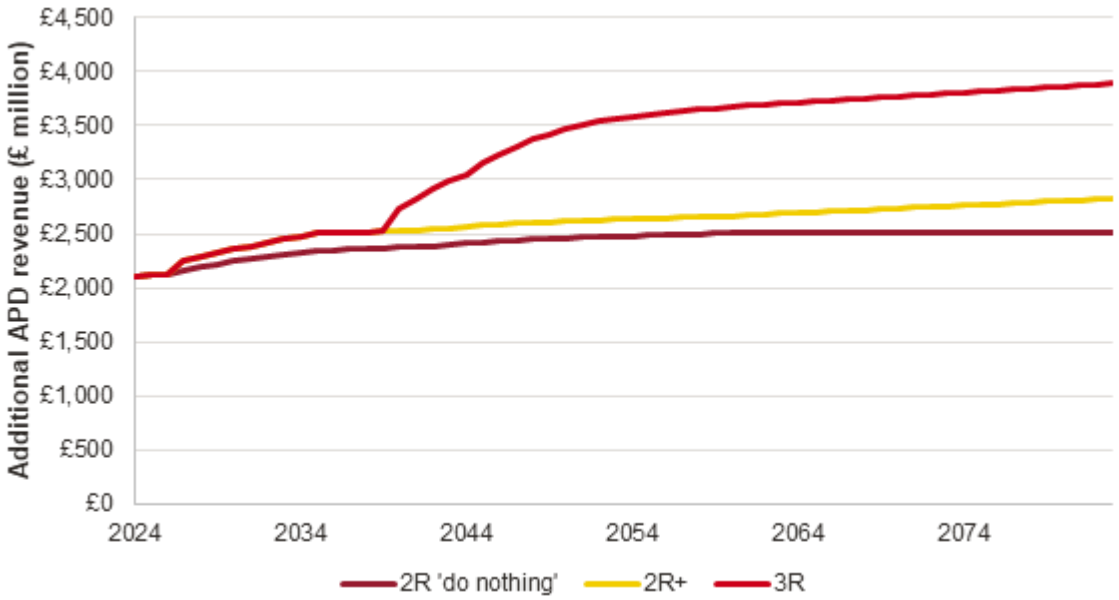
Source: Frontier analysis based on the DfT's 2017 UK aviation demand forecasts

Distilling this down to a general rule, we use a displacement factor of 40% - i.e. for every 1% increase in demand at Heathrow, we assume 0.4% is actually demand that has been displaced from other UK airports. Therefore, in the context of APD, we need to take into account that not all of the extra APD generated at Heathrow will be new APD.[49]

The charts below show our results for the two expansion scenarios:

[49] In principle, expansion at Heathrow may also lead to different passenger routings – e.g. instead of flying LGW-MAD-JFK a passenger may fly from LHR-JFK directly. This may change the amount of APD payable. However, for simplicity we have not sought to model this route switching impact.

Figure 34 Extra APD following expansion



	NPV of additional APD above 'do nothing' (£m)	NPV of additional APD above 'do nothing' with 1% growth in rates (£m)
2R+	£3,700	£4,800
3R	£14,400	£20,300

Source: Frontier analysis based on the DfT's 2017 UK aviation demand forecasts

Picking 2050 as a focus year, we find that under the 3R scenario, total APD receipts at Heathrow will be around £1 billion per annum greater than under the 'do nothing' scenario. (This takes into account that not all of the extra demand at Heathrow will be additional, and 40% will be displaced from other UK airports). This equates to £14 billion in NPV terms over a 60 year appraisal period. This is also based on assuming constant APD rates. If we assume APD rates increase by 1% per annum, this increases the NPV to £20 billion above the 'do nothing' scenario.

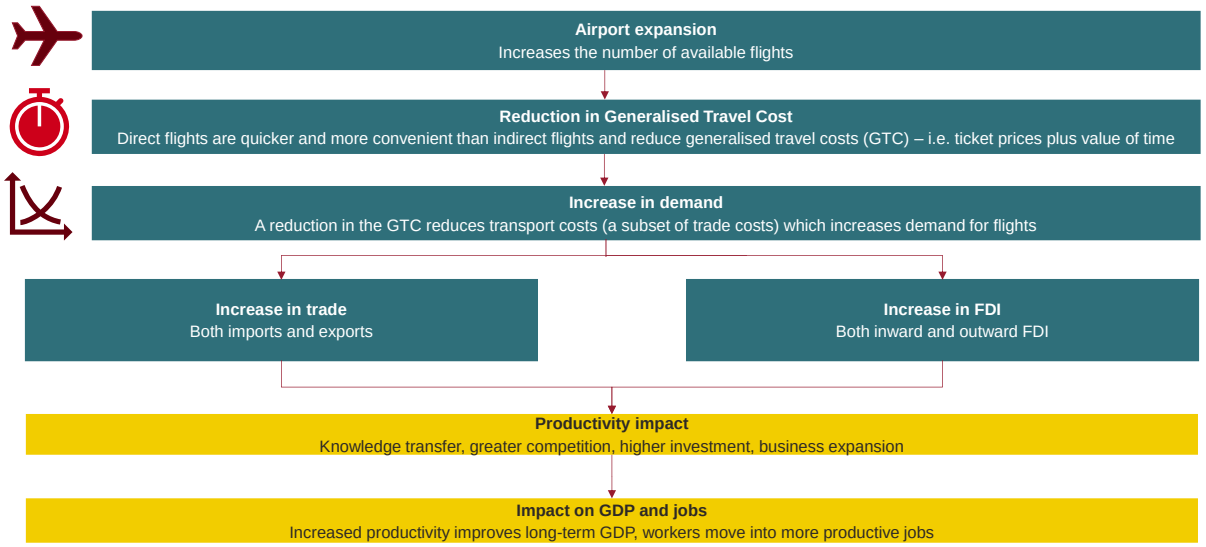
As discussed earlier, we note that strictly speaking APD, as a tax, is a transfer: government benefits from it, but it is ultimately paid by consumers. Therefore, there is an argument that it should not be included in the CBA. The figures estimated above relate to a level of economic activity that can either be captured by government, in the form of tax, or returned to passengers in the form of lower ticket prices. However, it is still important to recognise that government would stand to generate significant extra revenue from expansion, and as a privately-funded investment, it would not need to contribute to the cost. Also, while APD is a transfer from passengers to HMT, expansion would lead to many new foreign passengers flying to the UK, passengers who might not have come to the UK without expansion. Therefore, the APD

associated with these passengers can be viewed as being additional from the UK's perspective and new money entering the country.

3.3.3 Wider economic benefits

We have considered how expansion at Heathrow could lead to increased business travel, which in turn could help facilitate more trade and investment for the UK economy, and how this in turn could lead to productivity spillovers and ultimately boost GDP. As discussed earlier, we note that there is no consensus on precisely how to estimate these impacts, and the science continues to evolve. The diagram below provides a high level overview of our approach, where the logic is broadly similar to the logic that underpinned the AC's analysis and is designed to capture the wider productivity effects described in the Green Book / WebTAG.[50]

Figure 35 How expansion leads to wider economic benefits



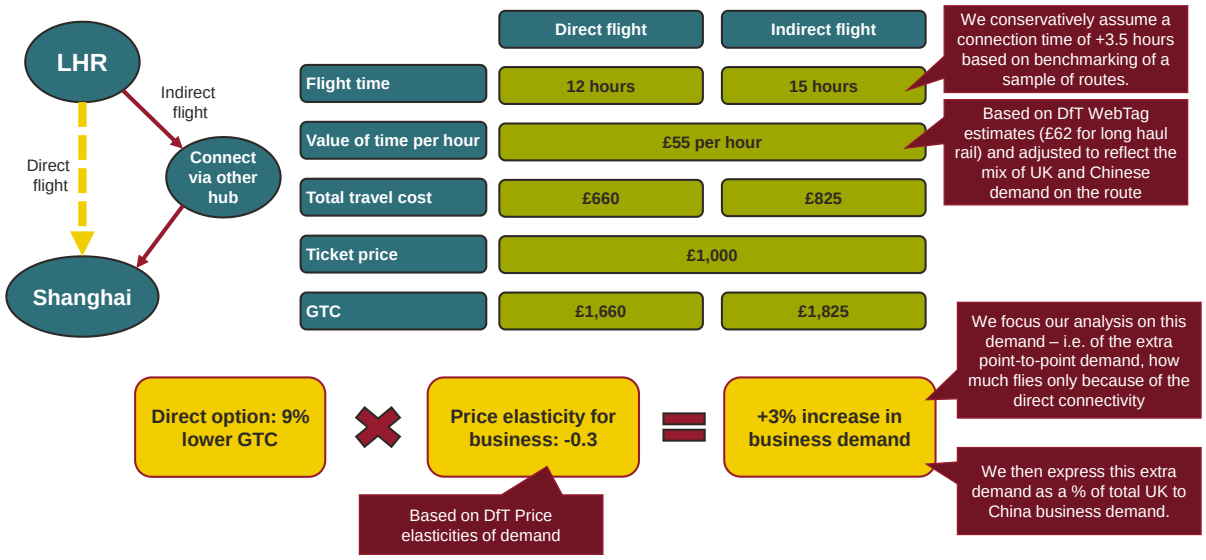
Source: Frontier analysis

At a high level, we first estimate the increase in *point-to-point* business travel following expansion, at the country-pair level (e.g. UK-China). Our approach is conservative. We do not take into account all of the 'gross' increase in business travel at Heathrow following expansion (i.e. the expansion scenario minus the do nothing scenario), as we recognise that under the do nothing scenario some of these passengers might still have flown indirectly to the destination, from Heathrow or from other UK airports. Instead, we focus our analysis on the extra business passengers who only fly because of the improved direct connectivity, and

50 For further information on our approach, please see section 4.2 in our previous report for Heathrow: https://www.caa.co.uk/media/avem5wts/hal-frontier-competition-and-choice.pdf

hence lower GTC, brought about by expansion. A high level example based on the Heathrow-Shanghai route is shown below.

Figure 36 How direct connectivity leads to greater demand - example



Source: Frontier analysis

Note: In this example, the generalised travel cost (GTC) of the direct flight is lower than that of the indirect flight. This leads to a boost in demand from passengers who previously were only able to fly directly.

As shown above, the calculation requires a PED for business passengers, which, for long haul, we assume to be -0.3.[51] This is based on the DfT's elasticity study. This figure is lower than the -0.9 referred to above in the section on ticket price savings. This is because whereas the analysis above required a PED for demand as a whole, this analysis requires a PED for business passengers specifically, and the evidence suggests that business passengers are more price inelastic than leisure and VFR demand. Also, in analysis on ticket price savings it was more conservative to use a *higher* PED (i.e. the ticket price savings are lower when using a higher PED). However, in this calculation, it follows that using a *lower* PED is more conservative – i.e. using a higher PED would imply a higher increase in demand, and hence greater benefits. As such, using the lower figure here is more conservative.

We then convert these increases in business travel into increased trade and investment, at the country level, using various elasticities. As discussed earlier, when carrying out the CBA, strictly speaking the benefit to the UK economy is not the extra trade and investment themselves – as this activity could simply be crowding out other business activity – but rather the fact that extra trade and investment leads to longer-term productivity spillovers for the UK.

51 Strictly speaking the analysis requires a *Generalised Travel Cost* elasticity of demand, which is slightly different to a *price* elasticity of demand, albeit price is a subset of GTC. However, there is limited evidence on GTC elasticities of demand. Also, in the DfT's NAPAM model it also uses price elasticities as a proxy for GTC elasticities.

We therefore convert the extra trade and investment into GDP, using other elasticities. The table below summarises our assumed elasticities.

Table 2 Elasticities used in wider economic impacts analysis

Elasticity	Long haul	Short haul
Price elasticity of demand for business passengers	-0.3	-0.2
Trade elasticity with respect to business travel	0.3	0.1
FDI elasticity with respect to business travel	0.3	0.1
GDP elasticity with respect to trade	0.3	0.3
GDP elasticity with respect to FDI	0.1	0.1

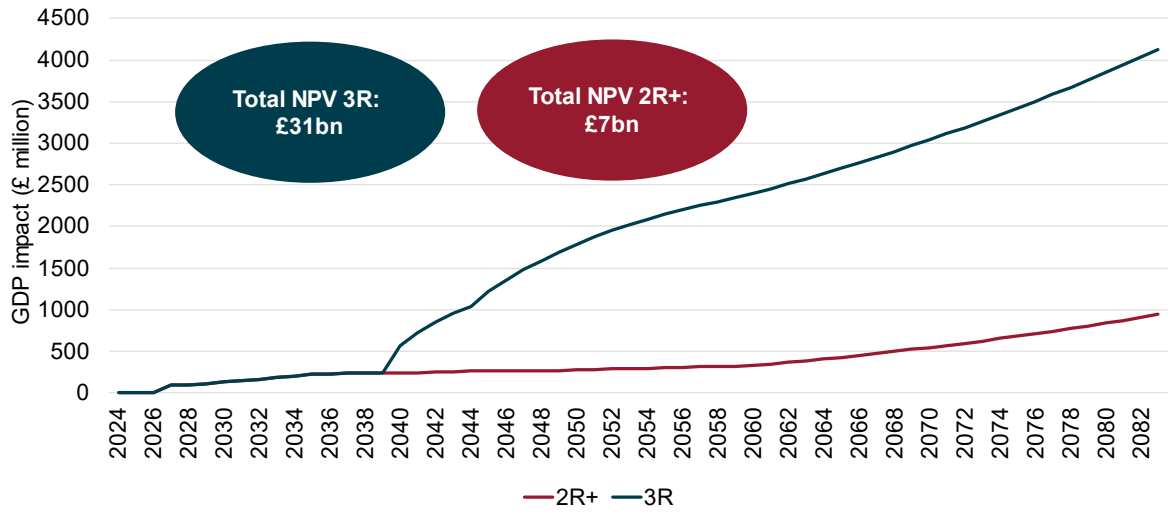
Source: Frontier analysis based on multiple studies, including: The DfT's PED estimates; the AC's econometrics analysis; HMT analysis on the impact of EU membership; Dhingra et al on estimating the trade impacts of Brexit.

Taking 2050 as a focus year, and focusing on the 3R scenario, we estimate that expansion would lead to the following impacts:

- Trade: £3.8 billion of extra trade (+0.11% at the UK level)
- FDI: £6.1 billion of extra FDI (+0.09% at the UK level)
- GDP: Converting these impacts into productivity spillovers, we estimate a GDP impact of around £1.8 billion (+0.04%)
- The USA, China, Hong Kong and India collectively represent approximately 60% of the total impact.

Over a 60 year time horizon, we estimate the GDP impact to be worth around £31 billion under the 3R scenario in NPV terms, and £7 billion under the 2R+ scenario. This is shown below.

Figure 37 Wider economic benefits - GDP impact over time (2024 – 2083)



Source: Frontier analysis

Expansion is therefore expected to deliver significant wider economic impacts. As mentioned earlier, the DfT did not include these impacts in its CBA – albeit we disagree with its reasoning. Therefore, including them in the CBA would significantly boost the business case of expansion.

3.3.4 Bringing the results together

Our analysis has focused only on a subset of the impacts of expansion. However, combining the results together we still see a clear picture emerge. Adding together our estimates of the ticket price savings, additional tax revenues, and the wider economic benefits gives an indication of the total benefits of the expansion options – in line with the benefits side of the AC's 'net present value' metric:

- For the 3R scenario, we estimate total benefits of £124 billion over the 60 year appraisal period.
- For the 2R+ scenario, we estimate total benefits of £33 billion over the 60 year appraisal period.

(We note that these estimates do not include passenger frequency benefits, reduced delays, consumer surplus for additional passengers, agglomeration, increased business output, or other non-APD taxes. However, these were relatively small in the AC / DfT analysis. This is therefore conservative.)

For these options to have a positive business case, the total benefits effectively need to exceed the total costs. The AC / DfT considered the following:

- Construction costs: We have estimates of construction costs, provided to us by Heathrow.

- Airline lost profits: We have not directly estimated this impact. In the AC and DfT analyses, lost airline profits are lower than the ticket price savings because, as the DfT notes, airlines "are, however, able to recoup part of *[the lost profits]* from being able to serve more passengers once the airport is expanded, and can earn higher fares if the airport becomes constrained again". We note that the DfT's estimate of airline lost profits was around 80% of the size of the passenger benefits. Therefore, as a high level rule, we have assumed that airline lost profits are equal to 80% of the ticket price savings that we have estimated. Further work would be needed to refine this estimate. However, as noted earlier, there is a question around whether this 'cost' should be included in the analysis given that these lost profits were essentially supernormal profits, above the cost of capital, due to capacity constraints, and also because many of the airlines at Heathrow are non-UK based, with profits taxed in other jurisdictions.

- Environmental costs: The DfT estimated that the cost of carbon, air quality, and noise was around £2 billion (2014 prices, or around £3 billion in 2024 prices) over the modelled period. We have not updated the AC's / DfT's estimates of the environmental costs. However, in terms of extrapolating this result, there are important factors to note:

  - As discussed earlier, the passenger forecast that underpinned the DfT's CBA was significantly greater than the 3R and 2R+ forecasts currently being considered by Heathrow. Therefore, all other things being equal, we would expect the DfT's estimate to be an overestimate – i.e. a lower forecast would imply less noise, lower emissions, and smaller impacts on air quality.

  - However, since the DfT carried out its CBA, the UK government has updated and increased its 'carbon values' – i.e. the value that it places on carbon emissions when carrying out CBA. The updated forecasts are now around 2-3 times greater than the older figures. The DfT's carbon costs were around 50% of the total figure estimated above, with air quality and noise representing the remainder.

  - Also, as discussed earlier, the AC / DfT analysis did not consider the impact of other non-carbon gases on the environment (albeit it did consider the impact of poorer air quality on local communities).

  - Taken altogether, we have taken the following the approach:

    - For the 3R scenario, we have conservatively decided to take the DfT's original estimates and multiple them by x2.5. This captures that the UK government's carbon values are now around 2-3 times greater than the older values assumed in the DfT's analysis. This leads to a figure of £7.5 billion (in 2024 prices) in NPV terms. We consider this approach to be conservative, because (i) the DfT's passenger forecast (and therefore associated environmental impacts) was significantly higher than the forecasts currently being considered by Heathrow; and (ii) we have applied this uplift not just to carbon costs, but also to the DfT's estimates of noise and air quality too, as a broad proxy for other impacts,

including non-carbon gases. Again, further work would be needed to refine these estimates.

– For the 2R+ scenario, we note that the size of the expansion is significantly lower than under the 3R scenario. And therefore the associated impacts would also be lower. We have therefore decided to take the figure estimated above for the 3R scenario and multiply it by 33% – reflecting the lower scale of the expansion option. This equates to a cost of £2.5 billion.

The table below summarises our results. We show the results for both expansion scenarios, and also under the 'net present value' metric (i.e. including all costs and benefits) as well as under the 'net public value' metric (i.e. excluding construction costs, airline lost profits, and government tax revenues).

Figure 38 Overview of 'bottom up' CBA results

2R+ scenario

	Costs	Benefits
Heathrow	£6 billion	
Passengers		£22 billion
Airlines	£18 billion	
Carbon, noise & air quality	£2.5 billion	
Economy		£7 billion
HMT		£3.7 billion
Total	£26 billion	£33 billion
Net present value	£7 billion	
Net public value	£27 billion	

3R scenario

	Costs	Benefits
Heathrow	£29 billion	
Passengers		£79 billion
Airlines	£63 billion	
Carbon, noise & air quality	£7.5 billion	
Economy		£31 billion
HMT		£14 billion
Total	£100 billion	£124 billon
Net present value	£25 billion	
Net public value	£103 billion	

Source: *Frontier analysis*

Note: *NPV over the period 2024-2083. 'Net present value' and 'net public value' are based on the appraisal metrics considered by the Airports Commission and the DfT. 'Net present value' is the sum of all benefits minus the sum of all costs – i.e. the widest appraisal metric. 'Net public value' essentially asks 'what does the public get out of the investment?'. It excludes (i) construction costs (as these are funded by Heathrow, a private company (with foreign shareholders); (ii) airline lost profits (as these were essentially 'supernormal' profits, brought about by capacity constraints, and many of these airlines are non-UK based with profits taxed in other jurisdictions); and (iii) taxes (as these are a transfer from passengers). Numbers may not add up exactly due to rounding.*

Our results suggest a positive business case for both expansion scenarios under the 'net present value' metric, and significantly more positive results under the 'net public value' metric.

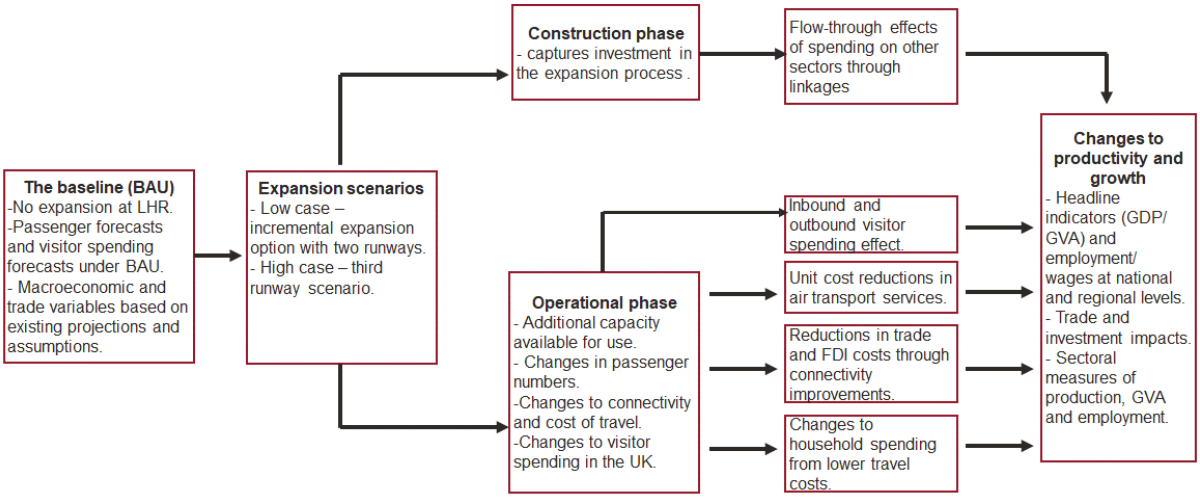
While our approach to estimating environmental costs is simplistic, viewed in a different light, our results suggest that under both expansion options there is a significant positive 'margin' (i.e. the benefits minus construction costs minus airline lost profits) remaining to cover environmental costs. And these margins are significantly greater than the environmental cost impacts previously estimated by the AC and the DfT.

3.4 CGE modelling

3.4.1 Overview of approach

In collaboration with the Centre of Policy Studies (CoPS), Victoria University Melbourne, we have carried out our own CGE modelling, which broadly follows the same logic and approach as used by the AC.[52] The diagram below provides a high level overview. More detail on the model is provided in Annex A.

Figure 39 Overview of CGE modelling



Source: Frontier analysis
Note: The model is calibrated using 2022 data

In the modelling, expansion at Heathrow is effectively treated as its own separate industry which links to the rest of the economy. Under the no expansion scenario, this industry essentially lies dormant. It then comes to life under the expansion scenarios where it starts to use factors of production (labour, capital and land), attract finance, and starts to buy and sell goods and services with the rest of the economy. The effects of expansion are presented as deviations from the 'do nothing' baseline. They project how the UK economy (and its regions) would evolve under the expansion scenarios relative to the 'do nothing' baseline scenario.

52 The CoPS model is in the ORANI/MONASH tradition which is solved using GEMPACK software. The model is calibrated to a 2022 database which distinguishes 65 industries, 65 products produced by the 65 industries, and 12 sub-national regions as defined at the first level of the NUTS classification.

Given the impacts of the expansion scenarios are reported relative to a baseline, establishing this baseline is an important first step in the modelling. The baseline projection incorporates publicly available forecasts for key variables such as real GDP growth, population growth, unemployment and labour force participation, terms of trade, carbon pricing and electricity generation. It also includes assumptions regarding the rate of labour-saving technological progress and autonomous improvements to energy efficiency. More information on the baseline projections are found in Annex A.

The expansion scenarios are then modelled on top of the baseline. Expansion 'shocks' the economy through capital expenditure, split out by type (e.g. spending on concrete and computer equipment, etc.), and operating expenditure, split out by type (e.g. labour, maintenance, etc.). These shocks are based on the cost forecasts provided to us by Heathrow.

As noted earlier, CGE modelling focuses on economic / market effects. As such it does not capture non-economic impacts such as environmental or social impacts. The modelling would therefore need to be viewed alongside the bottom up impacts described earlier.

We model two distinct phases:

- The construction phase: This is when the expansion 'industry' comes alive for the first time and starts interacting with the rest of the economy. The net impact on the economy depends on the balance between 'crowding in' and 'crowding out' effects.

Box 2: Crowding in versus crowding out

CGE modelling recognises that there are supply side constraints in the economy. An expansion in one sector may impact positively on other sectors ('crowding in') but also lead to negative impacts too ('crowding out') by soaking up resources and changing relative prices. The main constraints are:

- *Borrowing constraints:* We assume that Heathrow expansion is funded by a combination of domestic sources within the UK and foreign sources (in the ratio 1:3). The reduction in domestic funding therefore either requires a reduction in spending in other sectors or an increase in domestic savings.
- *Constraint on the availability of foreign currency:* Extra air travel leads to increased spending in the UK from foreign travellers and increased spending abroad from UK travellers. This impacts on the demand for GBP and foreign currencies, and hence exchange rates. An appreciation reduces the competitiveness of the UK's traded goods abroad, leading to a loss of exports and increased import penetration in local markets. On the other hand, a depreciation boosts the attractiveness of exports.
- *Constraints on the supply of labour of different skills:* The increase in visitor spending in the UK pushes up the demand for tourism-related skilled labour. Therefore wage rates increase, increasing the production costs of all industries in the UK economy. Industries facing international competition may be unable to pass on these cost increases without losing sales.
- *Constraint on government borrowing:* Heathrow expansion could potential lead to some public investment in infrastructure services. We assume that when this occurs the government attempts to keep its budget balanced. Therefore, Heathrow expansion is accompanied by small reductions in public spending elsewhere, sufficient to offset any increased spending related to Heathrow.

The ability of CGE modelling to take these constraints into account is one reason that makes them more reliable than traditional input-output analyses based on multiplier effects.

- The operational phase: This follows the construction phase and captures the impact of the extra traffic. This leads to the following effects:
  - An increase in inbound and outbound passenger numbers. This leads to changes in consumer spending, which in turn changes patterns of economic activity.
  - Changes to travel costs also lead to changes to household spending, and affects the overall budget constraint faced by households.
  - Improved connectivity / lower congestion reduces trade costs faced by businesses, which in turn facilitates trade flows (both exports and imports). As discussed earlier, in the first instance, increased exports raise GDP, while increased imports reduce GDP. However, over time, increased *openness*, measured as the sum of imports and exports, increases productivity which in turn boosts economic growth. There is a long

standing empirical relationship between trade openness and productivity. Research has focused on estimating the responsiveness of productivity to openness, and found that a 1% increase in trade openness can increase productivity by up to 0.7%. In this modelling, we use a value of 0.3% for the productivity uplift, which is consistent with the AC modelling.

The overall net impact on economic growth (as measured by GDP) will depend on the balance between crowding-out and crowding-in effects.

3.4.2 Results

The table below summarises our results. As noted, our results are reported as deviations relative to the baseline projections. The first two columns report the cumulative differences between the expansion scenario (2R or 3R) and the baseline projection for the variable in question over the period 2024-2050. The third and fourth columns focus on the results in 2050 only, and again these are expressed as differences relative to the baseline projection for that year

Table 3 Summary -of CGE modelling results

	Cumulative net impacts 2024-2050, relative to the baseline.		Impact in 2050 relative to baseline	
	2R+	**3R**	**2R+**	**3R**
Real household consumption (£m, 2022 constant prices)	17,486	41,143	2,012 (0.07%)	10,800 (0.39%)
Real investment (£m, 2022 constant prices)	12,382	39,187	343 (0.04%)	3,187 (0.4%)
Real government consumption £m, 2022 constant prices)	6,467	15,553	769 (0.07%)	4,095 (0.39%)
Real international exports (£m, 2022 constant prices)	11,783	19,186	1,632 (0.18%)	9,943 (1.09%)
Real international imports (£m, 2022 constant prices)	18,901	48,630	1,589 (0.11%)	10,897 (0.77%)

	Cumulative net impacts 2024-2050, relative to the baseline.		Impact in 2050 relative to baseline	
	2R+	**3R**	**2R+**	**3R**
Real GDP (£m, 2022 constant prices)	29,213	66,440	3,167 (0.08%)	17,129 (0.43%)
Employment - head count (total worker-years from 2024-2050)	48,925	238,532	444 (0.001%)	14,994 (0.04%)

Source: Frontier CGE modelling
Note: 2024-2050 impacts expressed in NPV terms, using a 3.5% discount rate.

Our analysis suggests that, by 2050, GDP is between 0.08% (2R+) and 0.43% (3R) higher than under the do nothing baseline. The cumulative monetary value of annual GDP uplifts over the period 2024-2050 ranges from £29 billion (2R+) to £66 billion (3R) in NPV terms.[53]

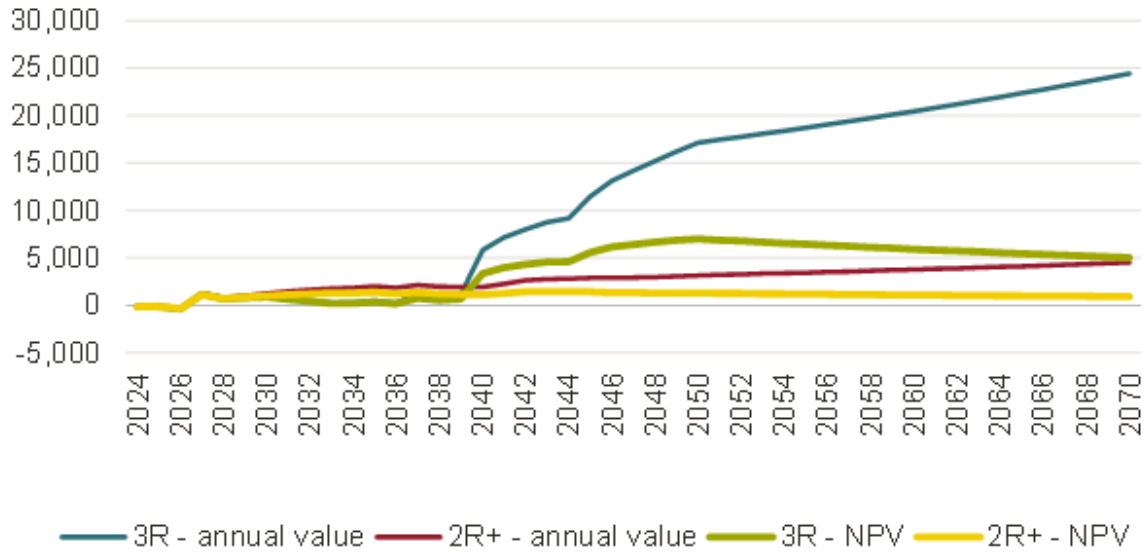
The overall effects on the balance of payments is negative: exports rise, but they rise less than imports do. This negative effect is consistent with the AC's CGE modelling. The increases in both exports and imports are the result of a combination of factors, notably the effects of spending patterns by inbound and outbound visitors, and the effects of connectivity on trade costs. The increase in both imports and exports increases the UK's openness to trade, which in turn delivers a significant boost to productivity over the modelling. The longer term productivity effects are significant and dominate, by a significant amount, the initial negative impact caused by the negative balance of payments. The productivity uplift, within the CGE framework, is associated with second- and third-order effects, which is an important reason why the reported GDP impacts in the CGE framework are significantly higher than our 'bottom up' wider economic impacts reported under Section 3.3.3.

Next, we have then extrapolated our results to 2070 for better consistency with the AC's results. By 2050, both expansion options can be considered to have reached their peak in terms of extra capacity coming online. Therefore, we extend the GDP impact beyond 2050 by taking the impact in 2050 and applying an annual growth rate of 1.8% (this is the growth rate assumed in the baseline, and at the very least, productivity impacts will be proportional to the size of the economy). Even with discounting, these additional years substantially increase the cumulative GDP impacts in NPV terms: by 2070, these are £51 billion under the 2R+ scenario and £184 billion under the 3R scenario. These numbers are more in line with the AC's results from its CGE analysis (£95–£184 billion in 2014 prices, or £127-£247 billion in 2024 prices),

53 The monetary values reported also reflect projected growth rates under the baseline. Variations in these projections would cause the monetary values to change in line with these variations, given that percentage uplifts in growth as a result of expansion effects (e.g. due to a percentage uplift in productivity) would be applied to a different base number.

albeit the 3R scenario is slightly lower as the passenger forecast currently being used by Heathrow implies a ramp up in demand that is lower and slower than that used by the AC.

Figure 40 GDP impact per annum (£m)



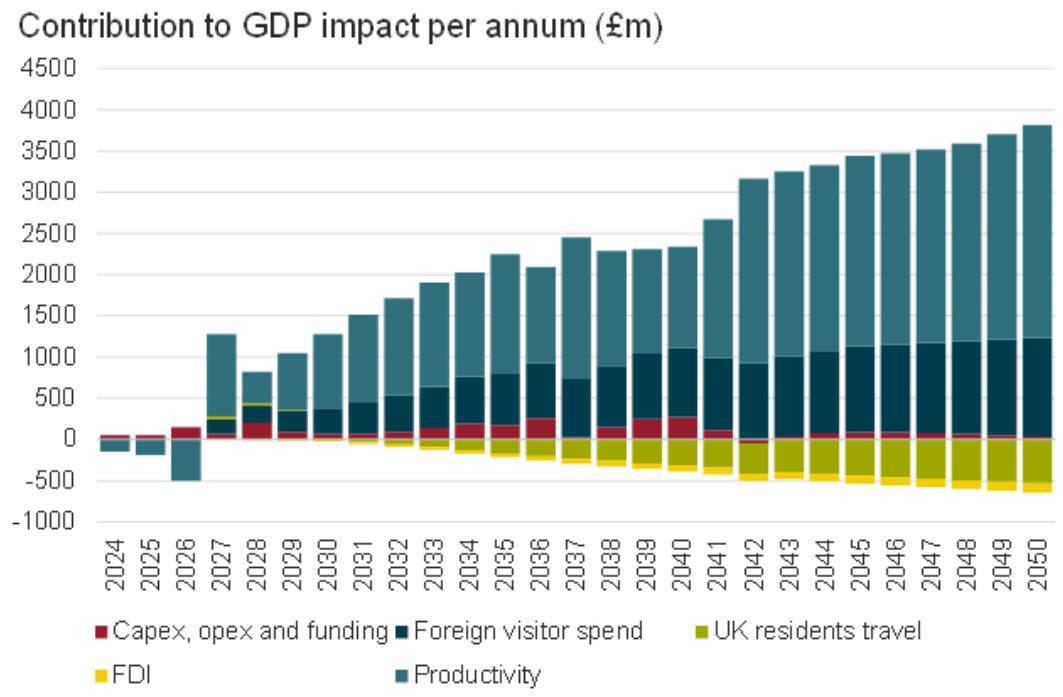
Source: Frontier analysis

These results focus on economic / market effects. As such, they do not include environmental or social impacts. As discussed earlier, we have not explicitly modelled these impacts. Instead, we have taken the DfT's estimates of environmental, noise and air quality impacts from its bottom up analysis (c£2 billion over the modelled period) and scaled them to capture that UK government has since increased its carbon values. Again, further work would be needed to refine these estimates. This suggests costs of around £7.5 billion (3R) and £2.5 billion (2R+) over the modelled period. Including these costs would still leave a very large margin.

3.4.3 Breakdown of GDP impact

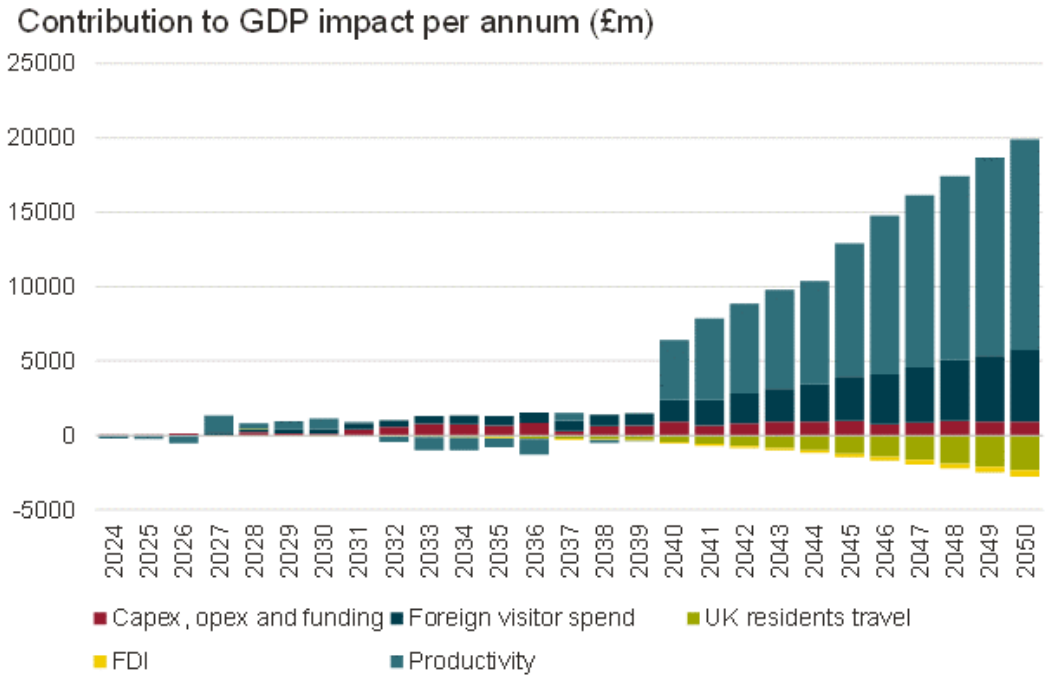
In the chart below we disaggregate the GDP impact into its component parts – both positive and negative.

Figure 41 Contributions to GDP impacts under the 2R+ scenario



Source: Frontier analysis

Figure 42 Contributions to GDP impacts under the 3R scenario



Source: Frontier analysis

Analysing the breakdown:

- Under both scenarios, the biggest contributor is through productivity effects, brought about by the increase in trade openness, which in turn boosts productivity. In our modelling, increased trade comes through the direct effects of expansion on exports (for example, by reducing transport costs to exporters, or increasing tourism exports), and through the trade-facilitating impacts on businesses by lowering their costs in concluding international transactions.

- Openness to trade increases productivity through a number of channels: it increases specialisation in activities in which the UK is more efficient; it generates efficiencies by increasing market size and therefore generating scale effects; and it provides a conduit for the diffusion of innovation and access to lower cost inputs. As reported above, these effects are captured in an empirically observed relationship between trade openness and productivity, and for the purposes of this modelling we use an estimated productivity uplift of 0.3% for every 1% increase in trade.

- The increase in productivity has a powerful influence on growth within the CGE framework because it has second- and third-order effects. An increase in real income per capita, following a productivity boost, then translates into increased consumption (by households and governments). That in turn further boosts GDP.

- Note that in the early years – during the construction phase – the productivity effects are negative. This largely reflects the fact that the capex uplift generates upward pressure on the real exchange rate, which in turn reduces trade openness and hence its contribution to productivity.

- Foreign visitor spending in the UK also generates significant positive impacts in the UK. The impacts reported are 'net' impacts in that they take into account crowding out effects. For example, increased visitor spending in pounds can put upward pressure on the exchange rate, depressing exports in sectors outside tourism. Spending by UK residents overseas has a net negative (short run) effect on GDP. (As noted earlier, the modelling captures market / economic effects only, and as such does not capture impacts such as wellbeing, which is an important metric in its own right, as well as how wellbeing can also impact on productivity). We note that the rest of the world is forecast to grow at a faster rate than the UK over the coming decades, and many developing countries are expected to move up the 'propensity to travel' curve at a faster rate than the UK, e.g. based on analysis of income elasticities of demand. Taken together, this suggests that the incremental demand at Heathrow will skew more and more to inbound demand over time, eventually leading to a tourism surplus, albeit the net effects still largely cancel themselves out, and are generally dwarfed by productivity effects.

- FDI has a marginal negative effect, reflecting the fact that outflows following expansion dominate inflows.

- The effects of the construction phase are very limited. Capex needs to be financed. In our modelling we assume that financing is split 1:3 between domestic and foreign sources.

Financing from domestic sources reduces domestic savings, and therefore reduces sources of funding for other forms of investment (that are in effect crowded out). The increased capex effect is also associated with an increase in the real exchange rate (reflecting capital inflows) and a decrease in external competitiveness – exports fall and imports increase.

3.4.4 Regional effects

We have then sought to break the results down by UK region. As reported in the table below, the expansion of runway capacity benefits all regions, albeit to varying degrees. The biggest gains are reported for London and the South East.

Table 4 Heathrow expansion: CGE modelling. Regional growth effects

	Cumulative net impacts 2024-2050, £m NPV		Cumulative net impacts 2024-2050, per head of population (£)		Share of cumulative impact		Annual impacts in 2050, £m	
	2R+	**3R**	**2R+**	**3R**	**2R+**	**3R**	**2R+**	**3R**
North-East England	544	1,259	201	464	3%	2%	67	384
North-West England	1,985	4,522	261	595	9%	9%	244	1,357
Yorkshire & the Humber	1,524	3,445	273	616	7%	7%	181	994
East Midlands	1,479	3,304	296	662	7%	6%	175	959
West Midlands	1,771	3,982	291	654	8%	8%	213	1,169
East of England	2,163	4,972	334	769	10%	10%	249	1,380
South-East England	3,386	7,688	357	811	16%	15%	399	2,208
South-West England	1,527	3,486	263	600	7%	7%	187	1,035
Wales	652	1,498	206	473	3%	3%	80	440
Scotland	1,407	3,212	258	590	7%	6%	171	935
Northern Ireland	373	834	195	437	2%	2%	46	257
Greater London	4,625	13,586	517	1,519	22%	26%	471	3,165

Source: Frontier analysis

The effects on productivity are the main reason why all regions benefit. Increased openness to trade encourages greater specialisation and scale. While this takes place to a greater extent in some regions than in others, greater productivity stimulates growth which then has knock-on effects through all regions because of interlinkages. This suggests that while London and

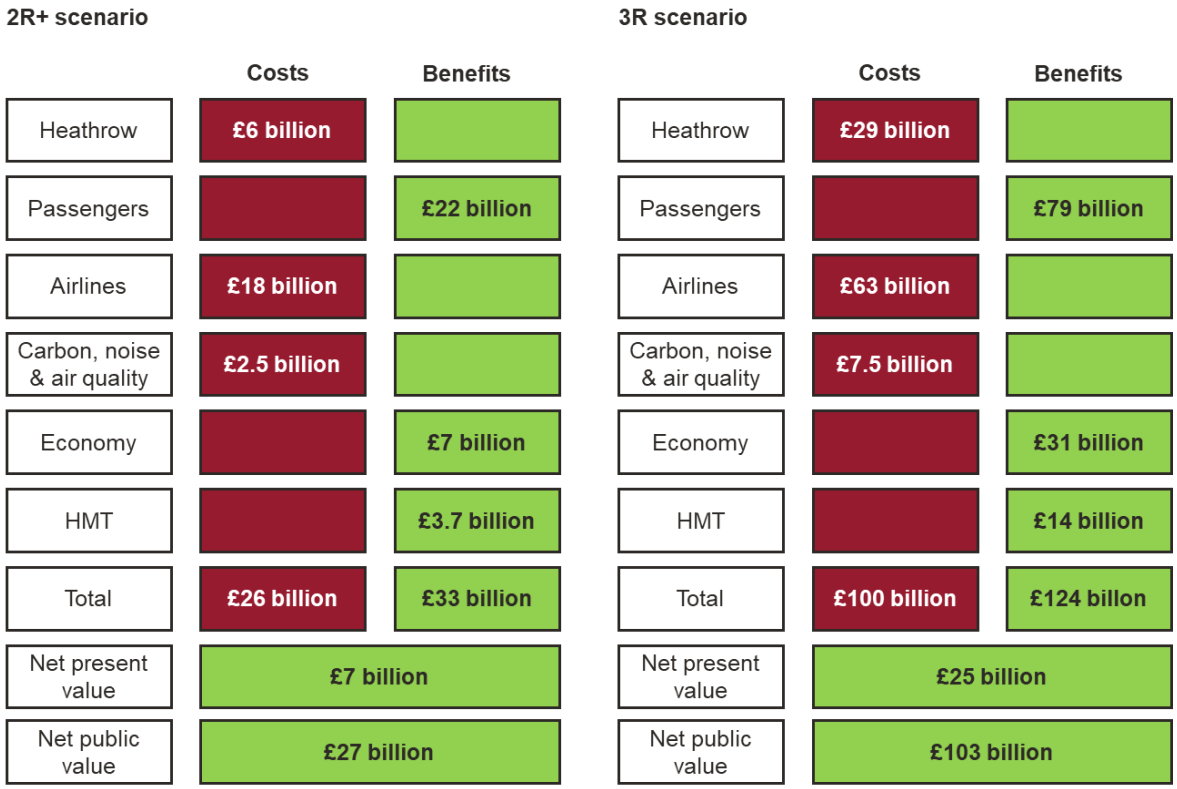
the South East are most likely to see the direct benefit of expansion, other regions in the UK also benefit.

4 Conclusion

We have been commissioned by Heathrow to consider the costs and benefits of different expansion options. In line with the approach taken by the AC, our analysis is split into two main parts:

- First, like the AC and the DfT, we have estimated a number of different cost and benefit types individually and in isolation from each other. This is not a formal update of the AC / DfT analysis – especially since many of the models underpinning that analysis are not publicly available. We have estimated some of the costs and benefits ourselves, based on detailed modelling. For others, we take the previous AC / DfT results and carry out high level extrapolations. Further work would be needed to update these other inputs more robustly. Like the AC and the DfT, we estimate that over a 60 year appraisal period, both expansion options deliver significant benefits, and that under both the 'net present value' and 'net public value' metrics considered by the AC there is a strong business case for both options.

Figure 43 Overview of 'bottom up' CBA results



Source: *Frontier analysis*

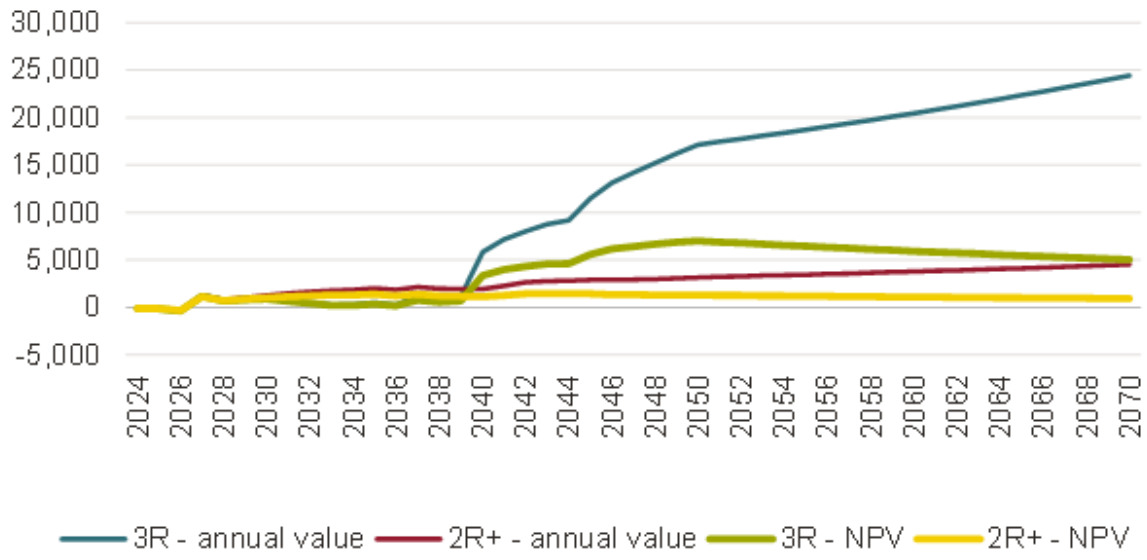
Note: *NPV over the period 2024-2083. 'Net present value' and 'net public value' are based on the appraisal metrics considered by the Airports Commission and the DfT. 'Net present value' is the sum of all benefits minus the sum of all costs – i.e. the widest appraisal metric. 'Net public value' essentially asks 'what does the public get out of the investment?'. It excludes (i) construction costs (as these are funded by Heathrow, a private company (with foreign shareholders); (ii) airline lost profits (as these were essentially 'supernormal' profits, brought about by capacity constraints, and many of these airlines are non-UK based with profits taxed in other jurisdictions); and (iii) taxes (as these are a transfer from passengers). Numbers may not add up exactly due to rounding.*

- Our approach to estimating environmental costs is simplistic (i.e. we have taken the DfT's estimates and inflated them to take into account that the UK government has increased its 'carbon values'). However, viewed in a different light, our results suggest that under both expansion options there is a significant positive 'margin' (i.e. the benefits minus construction costs minus airline lost profits) remaining to cover environmental costs. And these margins are significantly greater than the environmental cost impacts previously estimated by the AC and the DfT.

- Second, like the AC, we have also carried out 'Computable General Equilibrium' (CGE) modelling. This modelling takes into account that the economy is made up of a number of interconnected sectors, and how expansion in one sector impacts on others, with a number of first-, second- and third-order impacts. The model considers impacts on the labour market, household spending, trade and investment, and exchange rates, etc., and seeks to distil the different impacts down into an overall impact on the UK economy.

  Under both expansion scenarios, we find very positive GDP impacts: +£51 billion under the 2R+ scenario (in NPV terms) and +£184 billion under the 3R scenario. These figures focus on economic / market effects only, and do not take into account environmental or social impacts. However, using our high level estimate of environmental, noise and air quality impacts, described above, we still see very positive net impacts overall. For the 3R scenario, these numbers are broadly in line with the AC's results from its CGE analysis (£127-£247 billion in 2024 prices).

Figure 44 CGE model - GDP impact per annum (£m)



Source: Frontier analysis

Taken together both pieces of analysis suggest that both expansion options would have a very large net positive impact on society.

Annex A Additional detail on CGE modelling

A.1 Model overview

The results presented in this report are based on projections from the 'UKGE' model. UKGE is a dynamic Computable General Equilibrium (CGE) model of the United Kingdom designed, in the first instance, to analyse the economic impacts of expansion at Heathrow. UKGE is built in the ORANI/MONASH tradition and is solved using GEMPACK software.[54]

At the core of UKGE is code for the ORANI model, described fully in Horridge (2000).[55] To that is added a range of new mechanisms required for the current project. The model is calibrated to a 2022 database which distinguishes 65 industries, 65 products produced by the 65 industries, and 12 sub-national regions as defined at the first level of the NUTS classification. Main features of the model are given below.

Table 5 Overview of model

Model summary	UKGE is a dynamic economic model set up to analyse, in the first instance, the economic costs and benefits of expansion at Heathrow. Data base is for 2022, and covers 65 industry sectors, 12 regions and 2 occupation types. Developed by the Centre of Policy Studies at Victoria University, Australia for Frontier Economics, UK.
Key features	• Based on a neo-classical Computable General Equilibrium (CGE) core, solved using GEMPACK software. • Industry specific capital and investment driven by dynamic relationships that relate capital supply to expected rates of return. • Full accounting for domestic margins, including passenger and freight transport and wholesale and retail trade. • Special treatment of travel, with foreign tourists and students buying bundles of tourism services comprising transport, accommodation, entertainment, etc. • Direct and income tax taxes recognised, along with the current accounts of the private household and government. • Modelling of land supply decisions across agriculture and forestry, allowing for transformation between different output products based on changes in relative prices. • A full range of technological change variables across primary factors (capital, land and labour) and individual products (e.g., fertilizer used in agriculture, financial services used in consumption, etc.). Also allows for changes in autonomous energy efficiency and electrification in the delivery of transport services (Battery electric vehicles replacing IC vehicles). • Top down modelling of output and employment changes in 12 UK regions, including the four main legal jurisdictions and 8 regions within England (London, Yorkshire and the Humber, etc.)

54 ORANI/MONASH models are large CGE models solved in percentage changes. Their origins lie in the work of Peter Dixon – see Dixon and Rimmer (2002). GEMPACK (General Equilibrium Modelling PACKage) is a suite of economic modelling software described fully in Horridge *et al.* (2018). It is especially suitable for CGE models, but can handle a wide range of economic behaviour.

55 Horridge, Mark (2000), "ORANI-G: A General Equilibrium Model of Australia", CoPS Working Paper OP-93. https://www.copsmodels.com/elecpapr/op-93.htm.

	• Full account for macroeconomic relationships that relate, for example, changes in the real exchange rate to production and exports of internally traded goods industries.
Key inputs and assumptions for baseline	• The Baseline is a control projection based on business-as-usual assumptions for growth drivers such as technological progress and population growth. Critically in the context of the current project, no future expansion at Heathrow is assumed. • It covers business-as-usual assumptions for: foreign-currency import prices, positions of foreign export-demand schedules; growth drivers (population, labour force participation and productivity), • Assumptions for growth drivers, including population, labour force participation and all-factor productivity. • Assumptions for key environmental variables (the uptake of electric vehicles, for example) reflecting global and UK efforts to curb Greenhouse Gas emissions.
Construction and operation of expansion at Heathrow	• The model tracks changes away from Baseline in response to the construction and operation of expansion at Heathrow. Critical inputs to the *Expansion* scenario include: - The value of capex by year and expenditure type (purchases of cement, steel, etc.) - Benefits and costs of operation including international visitor spending which is additional to Baseline levels, additional spending abroad by UK residents who otherwise would not travel overseas, foreign holiday cost reductions due to greater access to cheaper carriers, etc.

A.2 Approach to baseline projections

The baseline, which starts in the year 2022 and goes out to 2050[56], is the control projection against which expansion scenarios are compared. The baseline incorporates information from specialist forecasting agencies. To accommodate this information in UKGE, some naturally endogenous variables are made exogenous. To allow the naturally endogenous variables to be exogenous, an equal number of naturally exogenous variables are made endogenous. For example, to accommodate the exogenous setting of the terms of trade, an all-commodity shift variable, naturally exogenous in UKGE but endogenous in the baseline simulation, imparts an equi-proportionate change in the positions of foreign demand curves sufficient to hit the required terms of trade target in each year

Table 6 Main variables included in baseline projection

Variable shocked	Comments
Real GDP	Made exogenous by endogenising all-industry, all-factor technological progress. In line with latest projections from the *Confederation of Business Industry,* UK GDP growth is projected to be 1.0 % in 2024. Momentum should continue in 2025, with GDP growth projected to be 1.9%. Thereafter, annual GDP growth begins at 2.2% (in line with the average pre-COVID growth rate for the previous ten years) before gradually declining to 1.6% by 2050 in line with the decline in population growth (see below).

[56] As noted in the introduction, the year of record for the model is the four quarters ending first quarter of 2022, which we refer to as 2022. Similarly "2023"is the four quarters ending first quarter of 2023, etc.

2020 is unaffected by COVID pandemic restrictions on economy activity. But 2021 and 2022 are affected. We assume that the COVID impacts are transitory, such that by 2023, which is when the policy simulations begin, activity in the UK economy has returned to levels that would have occurred in the absence of COVID.

Population and working-age population	In line with current *Population projections by the Office for National Statistics – United Kingdom*. Series used is labelled "Principal projection, 2021-based. Data were downloaded from the Office of National Statistics (2024 – see reference list).
Participation and Unemployment rates	Both are assumed not to change between 2023 and 2050. Thus employment grows in line with labour force which grows in line with growth in the working-age population (see above). Employment growth is accommodated by endogenous annual shifts in the real wage rate
Labour productivity	Labour-saving technological change improves at an average annual rate of 1.2% which is in line with the average improvement observed in the ten years prior to COVID. All else equal, this reduces the improvement in all-factor technological progress required to achieve annual real GDP growth targets.
Terms of trade	No change is assumed. Foreign-currency import prices are fixed, including the price of oil. Foreign-currency export prices are also fixed *via* endogenous outward shifts in world demand schedules for UK exports
Carbon price	Applies to all sectors and to all sources of emissions. Price rises in real terms from 59 BP to 138 BP. Year to year projections are based on data for *modelling assumptions* (Net Zero strategy) reported in Department of Energy Security and Net Zero (2023 – see reference list)
Electricity generation	Annual projections for generation from renewables and non-renewables are taken from Statista (2024 – see reference list). These data show that in 2022, renewables were the largest source of major power producers' electricity generation in the UK, at 135 terawatt-hours. This figure is projected to more than double by 2040, reaching 291 terawatt-hours. In contrast, electricity generation from natural gas is expected to decline from 100 to 27 terawatt-hours.
Autonomous energy improvement	Improves for all final energy types (coal, gas, refined oil and electricity) by 1% per annum
Foreign visitor arrivals and resident foreign departures from Heathrow	Baseline numbers for visitor arrivals and resident departures through Heathrow are exogenously set to projections provided by Heathrow Airport

Table 7 Projections for key baseline variables (%)

Variable	2022 to 2030	2030 to 2040	2040 to 2050	2022 to 2050
Real household consumption	2.6	2.3	3.2	2.6
Real government consumption	2.1	1.9	2.3	2.1
Real investment	1.0	1.1	3.2	1.8

International export volume	-0.1	0.4	1.4	0.6
International import volume	1.7	1.7	2.6	2.0
Real GDP	2.0	1.9	2.5	2.1
Employment	0.4	0.4	0.4	0.4
Real wage rate	0.9	0.7	0.4	0.6