TEG TRANSPORT ECONOMISTS' GROUP

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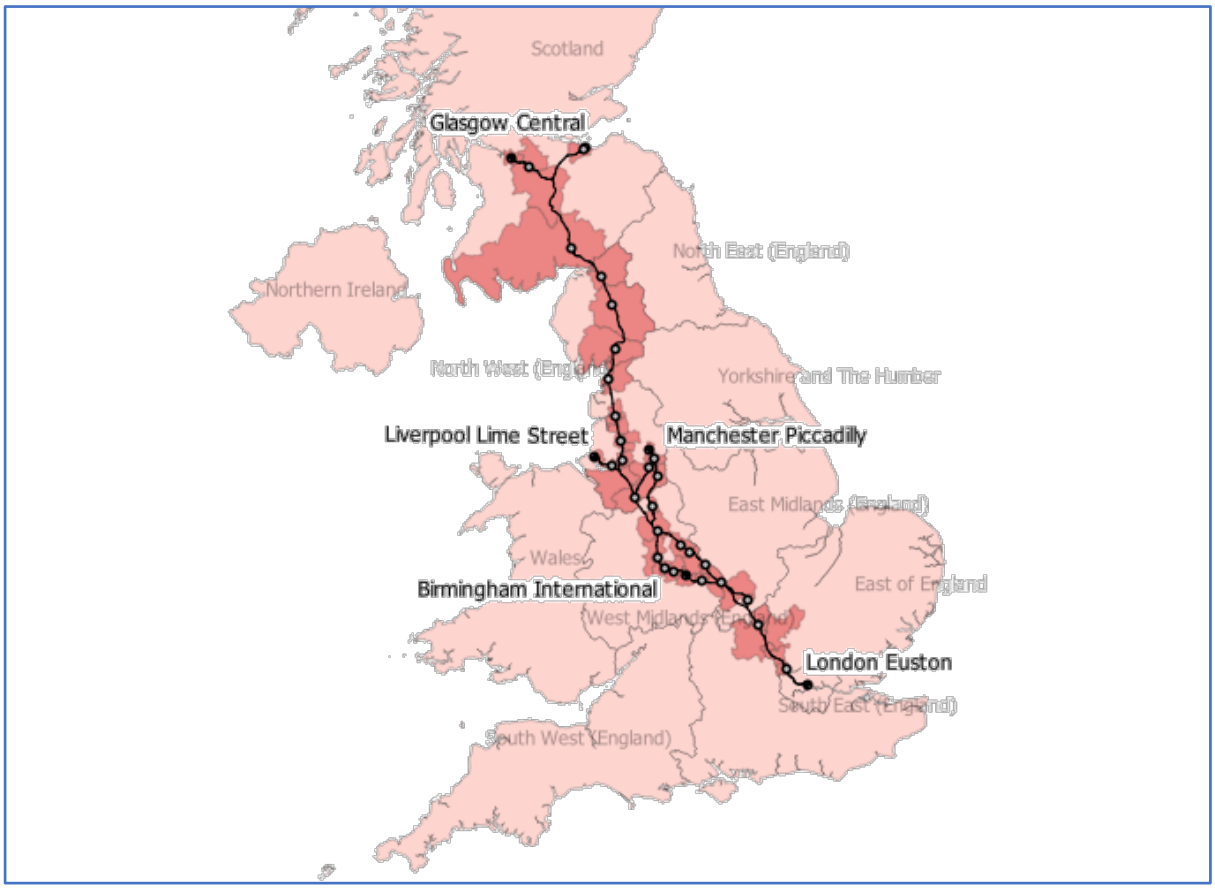

Editor Peter Gordon

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TEG TRANSPORT ECONOMISTS' GROUP

Understanding and quantifying transformational impacts from transport interventions

Milla Hamunen (Department for Transport) and
Csaba Pogonyi (Arup)

Online

24 January 2024

Introduction

The Department for Transport (DfT) had appointed Cambridge Economic Policy Associates (CEPA) and Ove Arup & Partners (Arup) to research how the context surrounding a transport investment may determine whether it leads to the economic or social transformation of an area. Milla had been working on wider impacts for around five years. Csaba focuses on using various quantitative evaluation techniques to understand the impacts of transport projects. Shafiq Pandor, CEPA's project manager, was also online and contributed to the meeting discussion.

The work

What do we mean by transformational impacts:

- How do these impacts materialise in transport programmes?
- What contextual factors are at play that might interact with the investment, such as local conditions, complementary investments, and policies?

Study approach

Milla outlined to approach to the study:

- A literature review examined:
    - the definition of "transformational impacts", which is now available in the Treasury "Green Book";
    - current evidence; and
    - contextual factors that may interact with the scheme to lead to transformation.

- Fifteen case studies examined:
    - whether they were transformational for measures such as patronage, productivity, employment, population growth and housing; and
    - how the context affected the outcome.
- Qualitative Comparative Analysis (QCA) was carried out to identify necessary and/or sufficient conditions that determine whether a scheme is transformational or not. This is a social research technique which can be used to identify conditions which are necessary and/or sufficient for an outcome of interest.
- A West Coast Main Line (WCML) Extension Study was used to quantify and attribute impacts for one case study.

The literature review

Csaba explained that the concept of transformational impacts only exists in the UK. They were first mentioned in the 2006 Eddington Transport Study[1], which included a broad definition that "*In some circumstances, projects may claim to deliver transformational economic benefits, which substantially change the geography of economic activity through the location of business and jobs.*"

Transport Analysis Guidance (TAG) now also includes a definition "*For regeneration and transformational schemes, in which transport is only one of a number of interventions or the land use impacts are expected to be diffuse over the study area, it may be appropriate to undertake supplementary economic modelling.*" Note that the TAG definition does not separate transformational transport schemes, as it deals with bundles of interventions. This can make it challenging to define transformational impacts.

The 2020 Treasury Green Book review referred to "*A fundamental structural change in the nature of the subject undergoing transformation. The scale of the change alone is not*

[1] Available online at https://webarchive.nationalarchives.gov.uk/ukgwa/20081230093524/http:/www.dft.gov.uk/about/strategy/transportstrategy/eddingtonstudy/

a defining characteristic. Being in practical terms virtually irreversible – in other words the removal of the intervention will not cause the system to revert to the original state."

In the context of improved transport infrastructure, however, the concept of "irreversibility" is problematic, as such infrastructure is rarely completely removed and, even if removed, had already influenced land use. The main example was the cuts to the rail network following the 1963 Beeching Report, in which some of the infrastructure removed had been in place for over a century, so it was difficult to isolate the transport intervention alone as "irreversible".

Also "*Transformational change is characterised by both tipping points (where relatively small interventions can be a catalyst for change) and leverage points (key nodes in the system where interventions are most likely to influence the system behaviour).*" This means that sometimes even small changes have very large effects, such as when they relieve bottlenecks or when new private sector investment is enabled or triggered.

Eliminating market failures, such as transport bottlenecks, may lead to positive externalities, such as agglomeration benefits, and to economic agents making additional investments.

A scheme is "transformational" if it:

- delivers **increases in connectivity** and/or **effective density**, manifested in **significantly increased usage of the transport network**;
- leads to **dynamic clustering** and/or **land use change**, empirically identified by a significant change in **sectoral employment shares** or **land use shares**; and
- leads to increases in at least one of: **employment**; **productivity per worker/firm**; **number of homes** and/or **land and property values**.

Impact evaluations of high-speed and urban rail, or railway stations, are rare:

- The evidence is mostly place-based, rather than people-based, effects.
- There are generally positive impacts on productivity, wages and land values.

- Population impacts are mostly for areas where population was growing before the intervention.
- Evidence on employment impacts is varied and suggests that displacement is present.
- Evaluations on the impact on land use change is rare.

The literature review also identified the contextual factors to be explored in the case studies. These are rarely analysed, but potential factors include: underlying socioeconomic factors; inclusion of local development strategies; use of social and human capita; and other related investments and wider policies.

Case studies

Milla described the rail and road transport schemes chosen as case studies, noting that the choice of cases studies was limited by the extent to which information had been collected and retained.

Table 1 overleaf lists the schemes, which were selected using:

- extensive desk-based research, reviewing documents including: business cases; evaluation reports; National Audit Office (NAO) reports; media articles; project monitoring reports from scheme sponsors and local authorities; academic studies; and parliamentary hearings;
- stakeholder interviews to obtain information on context and outcome; and
- for three programmes, primary quantitative analysis to provide the context to quantify, but not attribute, change after the intervention.

The two main outputs were a systematic overview, and hypotheses tested by Qualitative Comparative Analysis (QCA).

The systematic overview of the 15 projects identified:

- the timeline, pre-existing character of the area, contextual factors and outcomes;
- employment, productivity, housing, regeneration and environment; and
- a retrospective theory of change to test the logic of the programme.

Table 1: Case studies

Mode	Case study
Tram or light rail	Greater Manchester Metrolink: • 1992, Phase 1, Bury & Altrincham via city centre • 2002, Phase 2, to Eccles via Salford • 2013, Phase 3a, to Rochdale, Oldham & Droylsden • 2014, Phase 3b, to Ashton, East Didsbury & Airport
	Jubilee Line Extension (London): • 1999, Westminster via Canary Wharf to Stratford
	Nottingham Express Transit: • 2004, Line 1, Hucknall to city centre • 2015, Line 2, Beeston & Clifton
	Sheffield Supertram: • 1995, Phase 1: three routes from city centre
Rail	Borders Railway
	Corby new station and rail service
	Edinburgh-Glasgow Improvement (EGIP)
	Falmouth rail improvements
	Kirkstall Forge new station (Leeds)
	Reading station redevelopment
	West Coast Main Line upgrade
High-speed	High Speed 1
	High Speed rail network in Spain
Road	Great Yorkshire Way
	Markham Vale
	Newark A46 improvements

The hypotheses tested were:

- unlocking residential transformation;
- economic transformation through unlocking regeneration; and
- economic transformation through labour catchment.

Were the light rail schemes transformational?

Milla selected the light rail projects as example schemes.

Manchester Metrolink provided evidence of transformation, but not everywhere, and not in every phase of the expansion:

- There was evidence of job creation within the city centre, but less evidence of job creation elsewhere. Some phases were associated with new housing and land value increases.
- The evidence from outturn patronage was more mixed. Passenger numbers exceeded expectations in the earlier phases but had not met expectations in the later phases.

The Jubilee Line Extension (JLE) also provided some evidence of transformation, but not everywhere:

- It facilitated development and job creation in areas such as Canary Wharf, but less so in Canning Town and West Ham. The evidence suggested that job creation largely benefitted migrants rather than the incumbent local population.
- There was evidence of new housing and land value increases.

The Nottingham Express Transit (NET) also provided some evidence of transformation:

- There was evidence of job creation and reduced unemployment.
- There was evidence of changes in land use, but this was difficult to attribute directly to the scheme.
- There was evidence of land value increases.

In contrast, the Sheffield Supertram provided limited evidence of directly attributable transformation:

- Outturn patronage was substantially lower than expected, and this continued to the late 2000s.
- There was limited evidence on job creation, housing and land values.

The schemes which had the most perceived success had:

- an existing culture of public transport usage; and
- integration of light rail with other public transport modes.

As examples from the case studies:

- Car dependency: commuting patterns in Sheffield were more car-dependent than in Nottingham or Manchester.
- Integration with other public transport: in Nottingham, the bus network was redeveloped to act as a feeder to NET, but in Sheffield the privately-owned bus operators chose to compete directly with the Supertram when it opened.
- Park and Ride facilities were seen by scheme sponsors and evaluators as valuable additions, but some evidence from Manchester Metrolink suggests that many Park and Ride users would have used public transport anyway.

Residential transformation

Transport connectivity can lead to the residential transformation of an area, but is most likely to occur in areas with a context of:

- poor housing accessibility, as measured by Index of Multiple Deprivation (IMD) domain; and/or
- specific actions to facilitate housing developments, such as releasing land, or zoning for developments around stations.

Manchester Metrolink's tram stops were planned for and sited in areas where new housing was being planned. Two locations were part of the Housing Marker Renewal Pathfinders programme (2004-2011).

Sheffield Supertram had very poor coordination between city planners and the South Yorkshire Passenger Transport Executive (SYPTE). For example, the line was designed to serve existing high density residential areas which, for other reasons, were subsequently demolished or turned into low density housing.

The West Coast Main Line (WCML) extension study

Csaba explained how a separate study was commissioned to look at the 2004-2009 West Coast Main Line (WCML) upgrade.

- Figure 1 shows the study.
- Figure 2 shows the approach to identifying impacts.
- Figure 3 illustrates the results for GVA, population and services share on the WCML, with the ECML as a control.

Figure 1: the West Coast Main Line (WCML) study area

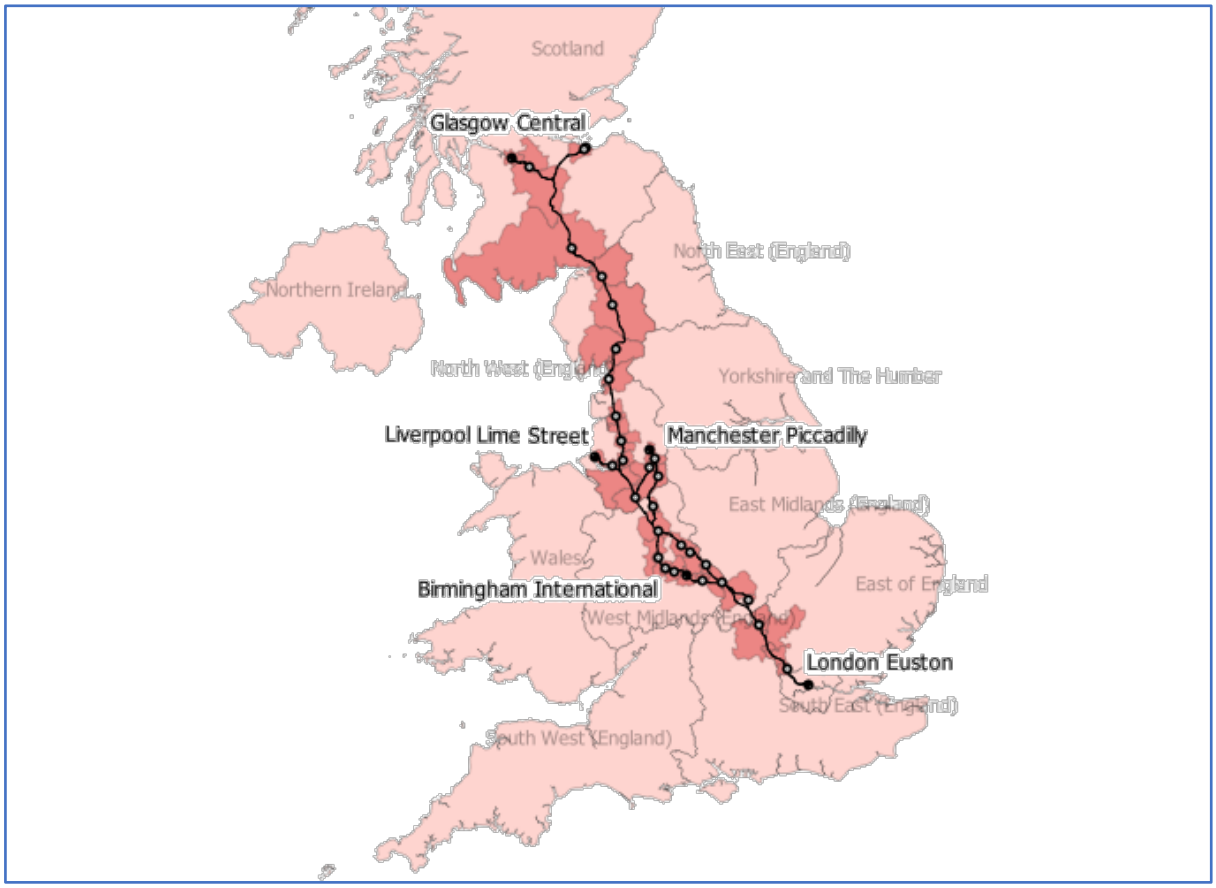
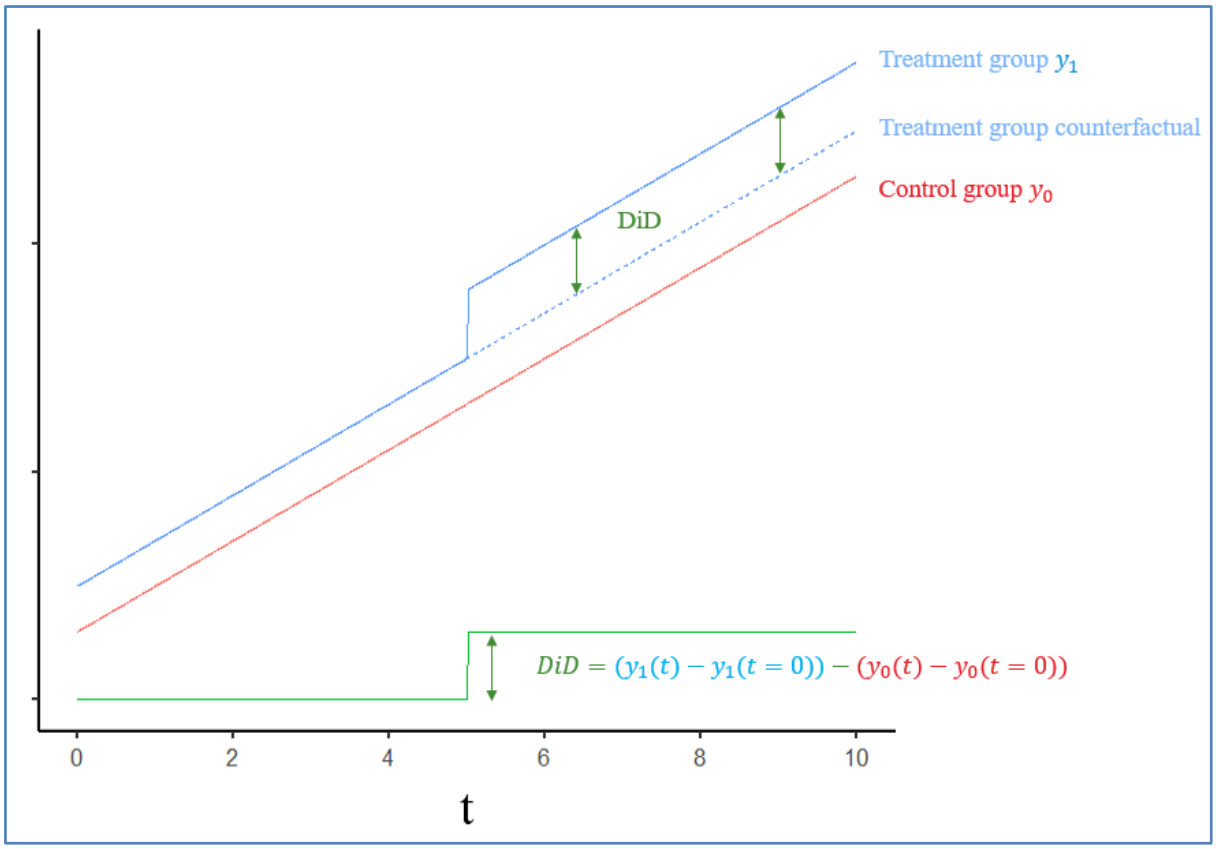


Figure 2: WCML: the approach to assessing impacts



Data was only available at local authority level, and from 2004 to 2016, which included the 2007–2008 Global Financial Crisis. Nonetheless, the study found positive impacts in local authority areas along the WCML, but these were mostly in the cities, and there were often similar effects on the ECML.

Table 2: Changes on the West Coast Main Line (WCML)

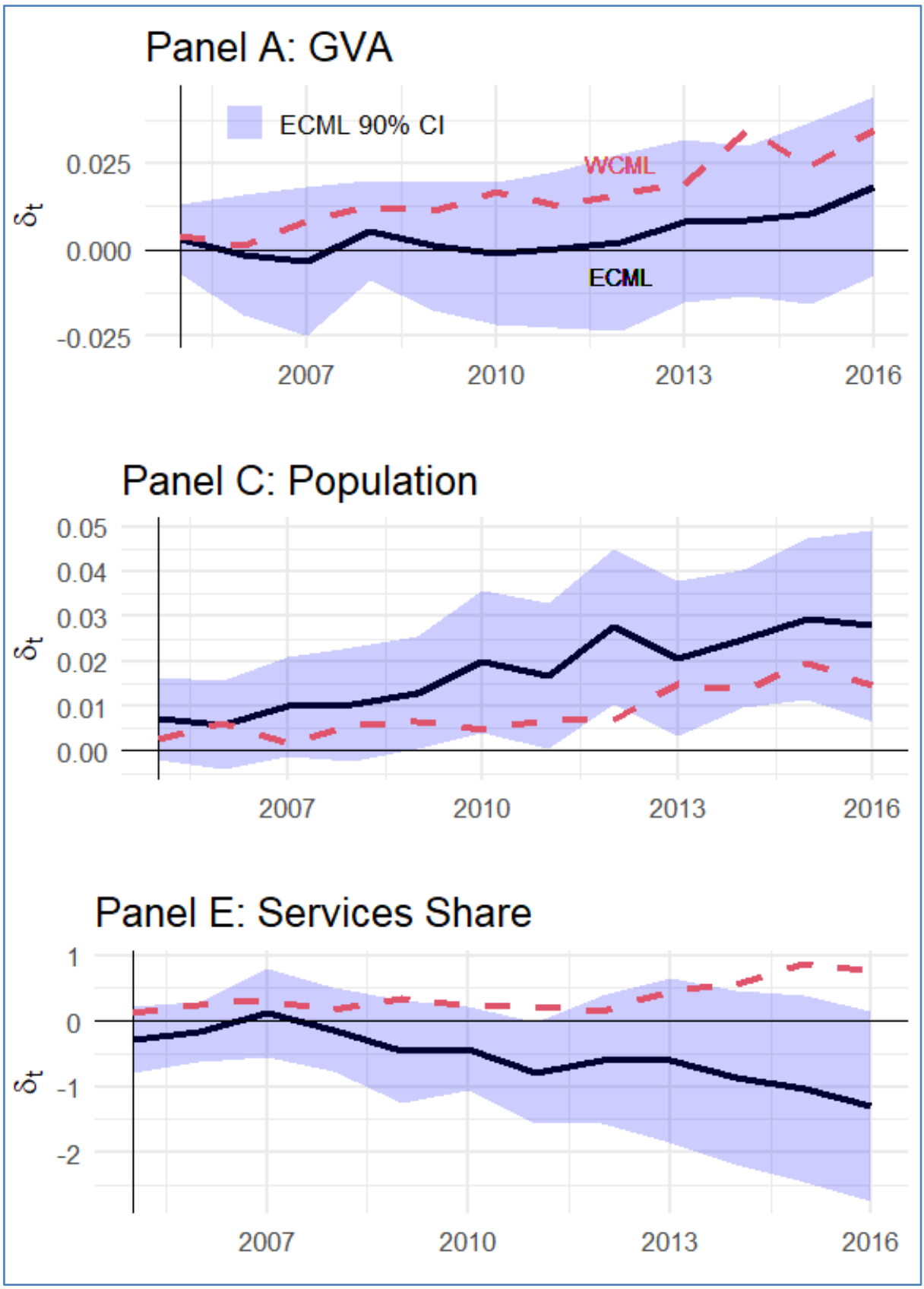
	All WCML	**WCML cities**	**WCML excluding cities**
GVA	+	+	
Population	+		
Service share	+		
Employment	+		
Share of age 26-39	+	+	+
House prices		+	-
Activity rate		+	
NCQ4 qualifications		+	
Share of age 65+		-	

Table 3: Changes on the East Coast Main Line (ECML)

	All ECML	**ECML cities**	**ECML excluding cities**
GVA		+	
Population	+		+
Service share		+	
Employment	+		+
Share of age 26-39		+	
House prices	+	+	-
Activity rate			
NCQ4 qualifications			
Share of age 65+		-	

In the event, as Figure 3 shows, changes on WCML and ECML were often not significantly different from each other.

Figure 3: GVA, population and services share and ECML control



The only significant results were the changes in sectoral shares, shown at the bottom of Figure 3.

Csaba noted that the WCML may have affected other areas positively:

- Many of the benefits may have been in London and the wider South East, which were omitted from the analysis.
- Much of the UK may have benefitted, making the ECML corridor ineffective as a control.

Furthermore, it could be argued that the upgrade was largely a catch-up (renewal rather than enhancement), in the absence of which local authorities would have fared worse.

Finally, it was possible that there were heterogeneous effects within the relatively large local authority areas, and that clearer results would have been found with more granular data.

In summary, Csaba said that transformational impact may have happened, but the attribution is not robust enough. Referring to the definitions of "transformational" change on page 3:

- It had definitely led to **significantly increased usage of the transport network**.
- However, the evidence was no strong on **land use change**, or actual economic impacts.

Summary of overall findings

Milla summarised the overall findings.

First, it was found that latent housing demand and action taken to facilitate housing regeneration together are sufficient for transformational impacts.

Second, however, it was impossible to find a clear pattern of cause and effect with economic transformation, but it was possible to identify factors associated with success, such as: background growth; commercial regeneration; regeneration plans; action to attract industries; and existing transport.

Third, to attribute impacts to interventions, the WCML study had shown that there is a need for more granularity in the data.

Fourth, transport investments in isolation are unlikely to contribute significantly to regeneration[2]. The most successful schemes had a background trend, private investment, and a clear plan and follow-through.

Fifth, on employment, commuting changed more slowly than anticipated in business cases. One explanation was that commuting changes occurred only with less frequency events, such as moving house or changing jobs.

Sixth, leisure travel was often more significant than anticipated in business cases.

Implications for policy

First, transport investments in isolation are unlikely to have transformational impacts and contribute significantly to growth and levelling up.

Second, transport is one of many considerations affecting location decisions for firms and households and is rarely the only barrier to an area's development.

Third, the most successful schemes were those delivered as part of a broader package of interventions which include:

- targeting areas where transport was a key barrier;
- coordination between stakeholders;
- good governance;
- a clear and actionable plan; and
- following through.

Fourth, changes to travel patterns take a long time to emerge, suggesting that the period over which schemes were evaluated should be extended to five or maybe even ten years.

Fifth, even if commuting patterns do not change, leisure travel can increase substantially and should not be overlooked in business cases. Careful consideration should be given to how

[2] The November 2023 TEG meeting discussed the linkage between transport and regeneration in the Thamesmead & Beckton Riverside Public Transport Programme Economic Appraisal.

leisure travel may reinforce or undermine strategic objectives, particularly if COVID led to a structural reduction in commuting.

Discussion

John Preston (University of Southampton) wondered about the WCML case study, and particularly what was the transmission mechanism from WCML improvements to corridor-level effects on GVA, given that few of the population in the corridor would use the WCML. **Tali Diamant** was also interested in transmission mechanisms, specifically to productivity. **Csaba** said that there was an increase in effective density, or job accessibility, giving economic agents access to more employment and economic opportunities. Agglomeration benefits found in literature include sharing (of inputs and outputs for companies), matching (of employees and employment) and learning (knowledge sharing within a larger pool).

Peter White commented that in Nottingham an initial consortium member in Nottingham Express Transit (NET) was Nottingham City Transport, which removed competing services when the tram opened, but reintroduced them when another consortium took over. **Csaba** had worked on NET and added that it served corridors that already had high public transport usage. **Peter** also noted that bus rapid transit (BRT) systems can produce very good benefit-cost ratios (BCRs) on the TAG criteria, as in the Crawley/Gatwick area and South Hampshire. Had the team considered BRT schemes as case studies? **Milla** said that the case studies had been chosen from a long list, but did not recall whether it included any BRT. **Csaba** said that data availability was a constraint, and **Shafiq** confirmed that there was a better evidence base for light rail than for BRT schemes.

Peter Gordon (Editor, The Transport Economist) asked how causality was determined in the case studies. **Csaba** said that this involved both desk research of previous studies and stakeholder interviews, including asking about any further work they had done, but there were no large questionnaire surveys. Determining causality was outside the scope of the analysis. **Shafiq** added that analysis of causality in existing studies was noted, but this was rarely definitive, so the study relied on triangulation and correlation.

David Metz noted the transformative effect of the Battersea Power Station extension of London's Northern line on formerly brownfield land. The extension did not appear to give the highest BCR but was preferred by the developers because it would give the highest property value uplift, on the basis of which they would make a contribution, and the Treasury agreed to an uplift in business rates. This meant putting together a range of stakeholders and generating funding from beneficiaries rather than just transport users. **Shafiq** agreed that this was an interesting example but was completed after the case studies were done. It contrasted with the Kings Cross redevelopment, also of brownfield land, where transport links were already good and there was no major transport intervention. He speculated that an intervention of this type would not have same impact in other cities with lower volumes of public transport use and more limited public transport networks. **Csaba** agreed: the literature supported the view that the high latent demand in London could justify schemes which would not be viable elsewhere.

John Dodgson asked whether the findings of the study could contribute to a future manual for scheme promoters and decision makers, either to designing schemes or assessing their benefits. **Milla** had hoped that the study could provide a checklist, which could be included in TAG: this had proved more difficult than expected but would still be desirable. **John** also asked if the study provided any evidence of the relative effects of rail and road schemes, few of which were included. **Shafiq** said that road schemes were harder to evaluate because their effects were diffuse, particularly compared to light rail schemes confined to an urban area or corridor. **Dick Dunmore** suggested that estuarial bridges such as the Forth, Humber and Severn had transformed connectivity between regions or sub-regions, and that the Lower Thames Crossing might have a similar effect. **Shafiq** agreed that these older schemes might have behaved more like new rail schemes, but they were found to be poorly documented. **Tom Worsley** said that there had been some relatively crude before and after studies of the road schemes that then dominated, such as of the A55 North Wales Expressway[3]. One finding had been that local firms interviewed

[3] Construction began in the 1980s, with the critical Conwy Tunnel opened in 1991.

before the scheme had been replaced by goods being shipped into North Wales from Manchester and Liverpool. **Dick** had worked on modelling and building the scheme, and it had been foreseen that the increased accessibility would favour larger and potentially more efficient firms outside the area. Similar effects had been found with the opening of the Skye Bridge. **Csaba** said that the issue of displacement is always there, but the impacts were often not properly understood. On the Jubilee Line Extension, for example, the number of firms did not change, but the more productive ones had moved closer to the stations and the less productive ones had moved further away, with an overall productivity gain.

Tony Fowkes (Institute for Transport Studies, University of Leeds) was interested in the reference to the Eddington Report, to which he contributed, and wondered if it remained available. **Csaba** agreed that it was "an amazing report" which he had used a lot.

Tom Worsley wondered how it had been concluded that the impacts identified were (additional) economic externalities of wider benefits rather than just a use of (direct) user time savings. **Csaba** agreed that this was a good question and that the evidence available could not readily disentangle these effects. **Shafiq** agreed, although one specific approach was that higher-than-forecast patronage was interpreted as possible evidence of land use change, demonstrating wider economic impacts, and conversely low patronage change might be evidence of the absence of this effect.

Tali Diamant had two thoughts. First, the theory of change could explore why things such as productivity change had not happened. Second, the materiality of a change in one mode might depend on what other modes were available, and it might be worth testing more for this sort of effect. **Shafiq** said that the QCA included some examination of where productivity did not materialise, but it was not possible to generalise the findings: similar contexts sometimes led to different outcomes.

John Preston queried the definition of transformational: was this about the scale of change, or about non-marginal changes that could not be forecast well with conventional models? On the WCML, the changes in both generalised cost of rail travel and the

population using rail may have been quite small: was this really transformational? **Csaba** said that the issue might be the removal of a small bottleneck or reduction of journey time below a key threshold, offering "a bigger bang for our buck"[4].

Sandy Fong asked in the chat about the potential scope for transformation in well-developed networks. **Csaba** thought this was a good question, but expected that bottlenecks could be found even in well-developed networks, such as with the major new road crossings.

Report by Dick Dunmore

[4] California Dreamin': The Feeble Case for Cluster Policies, Gilles Duranton, University of Pennsylvania, 2011.

The challenges and costs of rolling out hydrogen aircraft

Peter Wiener (Steer)

Arup

28 February 2024

Introduction

Peter introduced himself as an Associate in Steer's Infrastructure and Asset Advisory division, focusing on aviation policy, regulation, and transaction advice. He has worked in the aviation industry for over 30 years, initially at British Airways but subsequently in consultancy, including 18 years at Steer. His background includes operational research and business administration, forecasting traffic demand, developing and reviewing business plans for airports and airlines, and a wide range of consultancy projects including operating costs, airport resilience and customer service and, in the last few years, decarbonisation of aviation.

Decarbonisation of aviation is extremely difficult, although there are also challenges to the decarbonisation of shipping. Much of the current effort focuses on Sustainable Aviation Fuel (SAF), renewable or waste-derived aviation fuel that meets sustainability criteria. The EU and the UK have legislated to require aviation fuel to include a proportion of SAF, while the US is subsidising SAF fuel production through tax credits.

The industry has identified hydrogen as an alternative fuel, but has not identified an optimal or viable path to its introduction. Peter would describe two studies, both of which created a scenario for the use of hydrogen, one focusing on the challenges to, and the other to the costs of, its introduction.

"Market update and impact of key green aviation technologies"[5] for the European Commission, was published on 14 March 2023. The study examined hydrogen and electric aircraft in Europe and

[5] https://op.europa.eu/en/publication-detail/-/publication/8253ad77-c21f-11ed-8912-01aa75ed71a1/language-en

worldwide and involved extensive stakeholder consultation. It developed a detailed hydrogen aircraft scenario. It then focused on the challenges to achieving the assumed rollout of hydrogen aircraft. The work was supported by the Deutsches Zentrum für Luft- und Raumfahrt (DLR), the German Aerospace Center.

"Analysing the costs of hydrogen aircraft"[6], for Transport & Environment and the European Climate Federation, was published on 24 May 2023. It focused on the scope for hydrogen-powered aircraft in Europe, with a simpler but broadly comparable rollout strategy. It then focused on the costs of achieving the assumed rollout of hydrogen aircraft. Steer was supported by the Institute of Environmental Technology and Energy Economics at Hamburg University of Technology (TUHH) and airport cost consultants Doig + Smith.

Peter would discuss in turn:

- assumptions on aircraft types and fleet replacement;
- challenges emerging from these assumptions;
- costs; and
- overall conclusions.

Assumptions: aircraft types

The European Commission study assumed that commuter aircraft with up to 19 seats could be in service by 2030, but Table 1 shows how larger aircraft which could make a material contribution to decarbonising aviation would not be in service until 2035. All aircraft must carry enough fuel to reach the destination and one or more alternatives, and to hold for a period before landing. These periods are typically 45 minutes for turboprops and 30 minutes for turbofans. Figure 1 shows these effective full ranges from Frankfurt (FRA) and Tenerife (TFS):

- From Frankfurt, they include Iceland and anywhere in Europe, North Africa and the Levant.
- From Tenerife, they include much of West Africa, but not Iceland, Scandinavia and central and Eastern Europe.

[6] https://www.transportenvironment.org/wp-content/uploads/2023/05/Study-Analysing-the-costs-of-hydrogen-aircraft.pdf

Table 1: Hydrogen aircraft design assumptions

	Regional aircraft	**Short to medium range aircraft**
Service entry	2035	2035
Seats	40-70-100	160-200-250
Technology	Hydrogen Fuel Cell	Hydrogen fuel
Type	Electric regional turboprop	Direct combustion turbofan
Cruise speed	Mach 0.55	Mach 0.78
Approach	New technology	Changed fuel type
Effective range		
Fuel both ends	1000 nautical miles	2000 nautical miles
Fuel one end	400 nautical miles	800 nautical miles

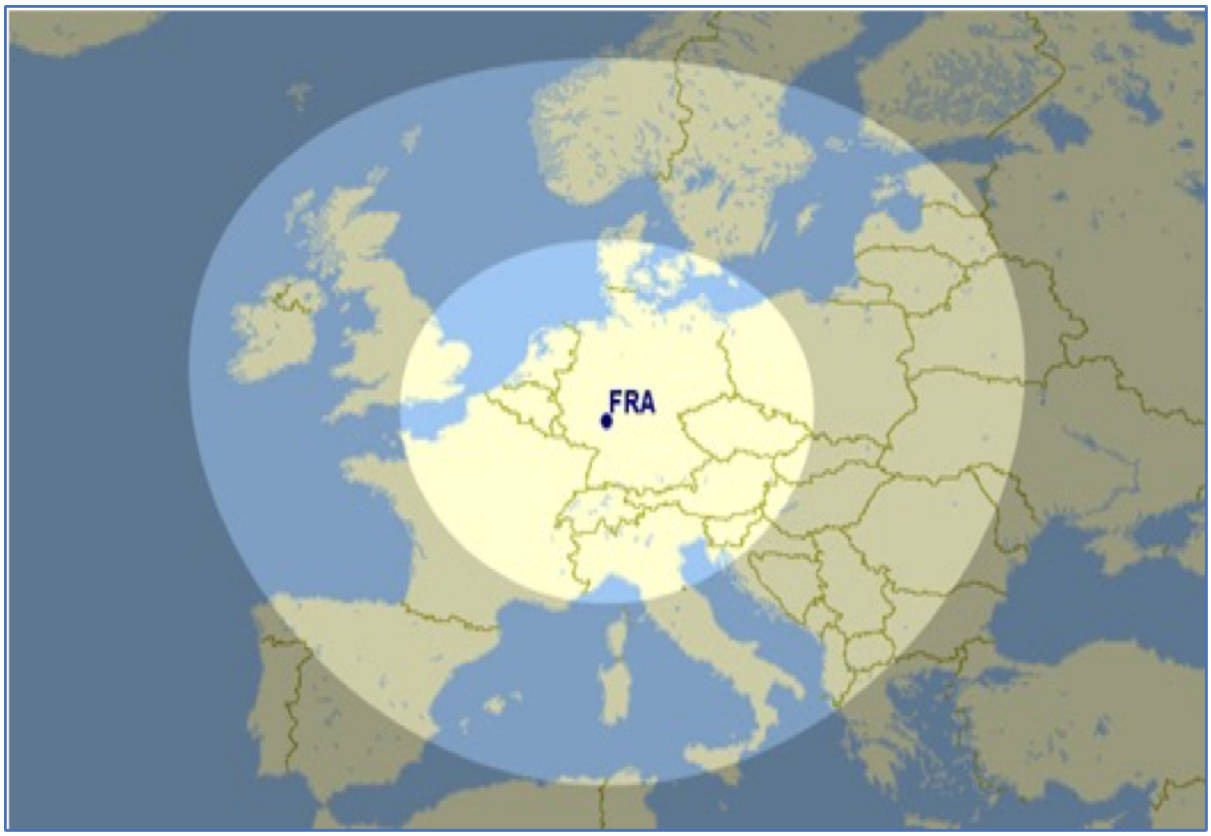
Figure 1: Hydrogen turbofan ranges from Frankfurt and Tenerife

Peter noted that there was a "chicken and egg" issue: would rollout be driven by the availability of hydrogen-powered aircraft or of hydrogen-equipped airports[7]? In principle, operations could begin at a single hub, from which departing aircraft would have to "tanker" sufficient fuel for the return flight.

Figure 2 shows the much lower effective ranges from Frankfurt if fuel was only available there:

- The 800 nautical range of a direct combustion turbofan covers most of the EU, but still excludes capitals such as Helsinki, Athens and Lisbon.
- The 400 nautical mile range of a hydrogen fuel cell would include fewer than half of the EU capitals.

Figure 2: Ranges with tankering from Frankfurt



Hydrogen has a higher energy density per kilogram than the current fuel, kerosene, but would need to be liquefied and kept at 20K (-253°C) in insulated tanks. However, liquid hydrogen still has a much lower energy density per litre than kerosene

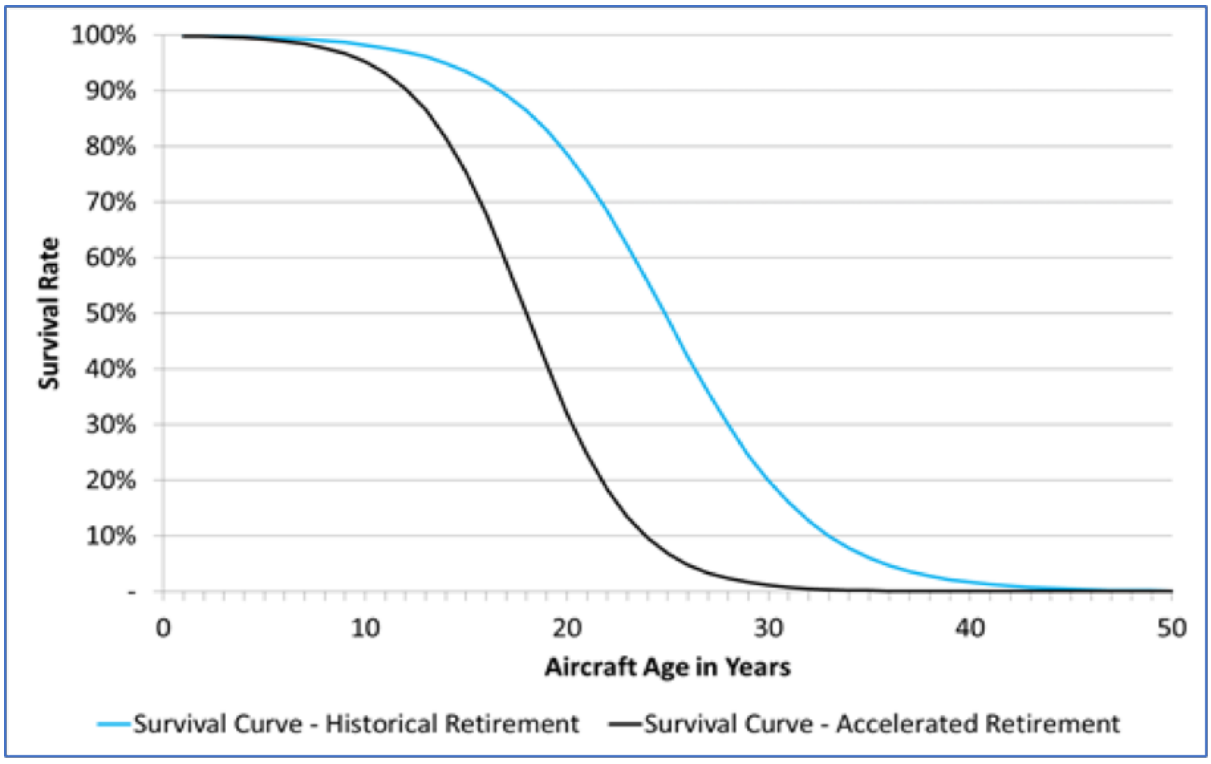
[7] The October 2023 TEG meeting on electric vehicles noted a similar uncertainty over whether rollout would be led or constrained either by vehicles or by charging facilities.

(8MJ/litre and 32MJ/litre respectively) and would therefore require tanks four times larger to store the same energy and deliver the same range. For short-haul aircraft, the fuel can be accommodated within tanks in the fuselage, while still allowing similar passenger loadings to current short-haul aircraft at the cost of a slightly longer plane. For long-haul aircraft, which use significantly more fuel, it is considered necessary to develop a new aircraft configuration, such as a blended wing body (BWB), which would take a long time to develop.

Assumptions: aircraft fleet replacement

Figure 3 shows the assumed evolution of the aircraft fleet. Historical average aircraft survival rates follow the blue curve, with 50% retired after 25 years and almost all retired after 40 years, often after conversion to, and use as, cargo aircraft. The study assumed that these accelerated to 50% retired after 18 years and almost all retired after around 30 years. This could be achieved through measures such as the proposed "scrapping rule" for green finance, but would by implication depress the values of existing fleets.

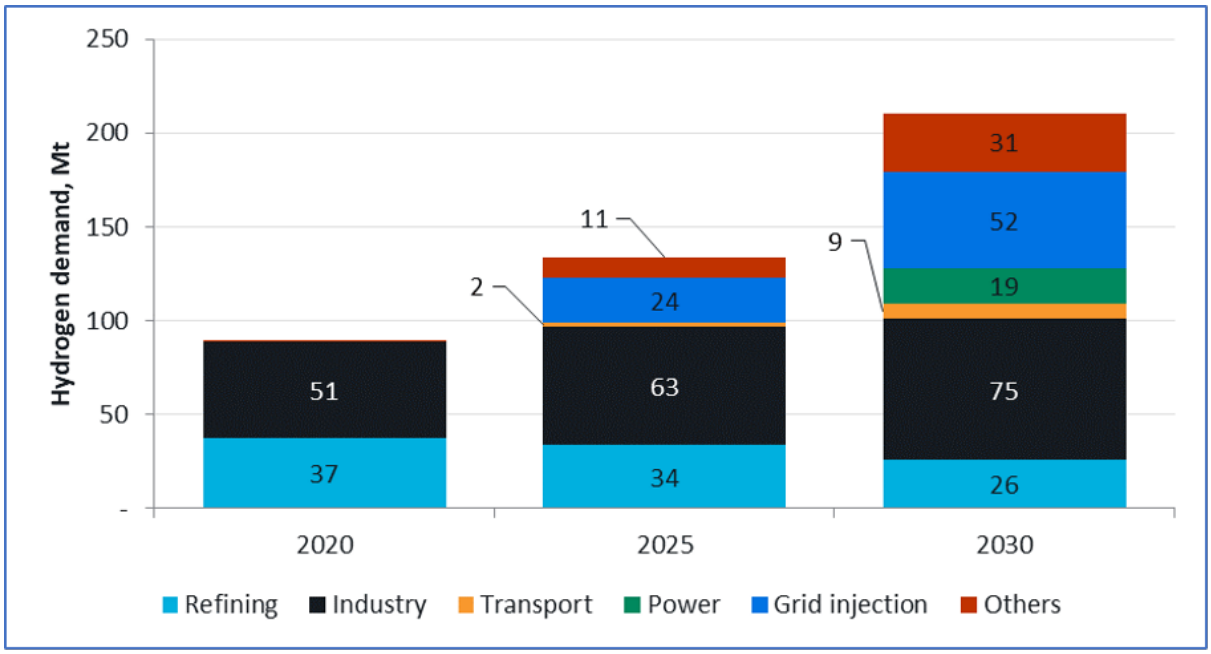
Figure 3: Historical and accelerated aircraft survival rates



Challenges: hydrogen production and distribution

Figure 4 shows forecast global hydrogen demand by industry.

Figure 4: Global estimated hydrogen demand by industry



Transport is a relatively minor contributor, with around 8% of total forecast demand (40MT of 528MT in 2050), but will have to compete with other industries such as steel production and hence will have to afford the market price they pay.

Figure 5 shows the proposed European Hydrogen Backbone (EHB) initiative, which would require a significant investment in new pipelines as well as repurposing existing pipelines for natural gas, which is mainly methane (CH_4). While the initiative exists, it could not be financially justified by, and will not prioritise, aviation needs.

Figure 5: The European Hydrogen Backbone (EHB) initiative

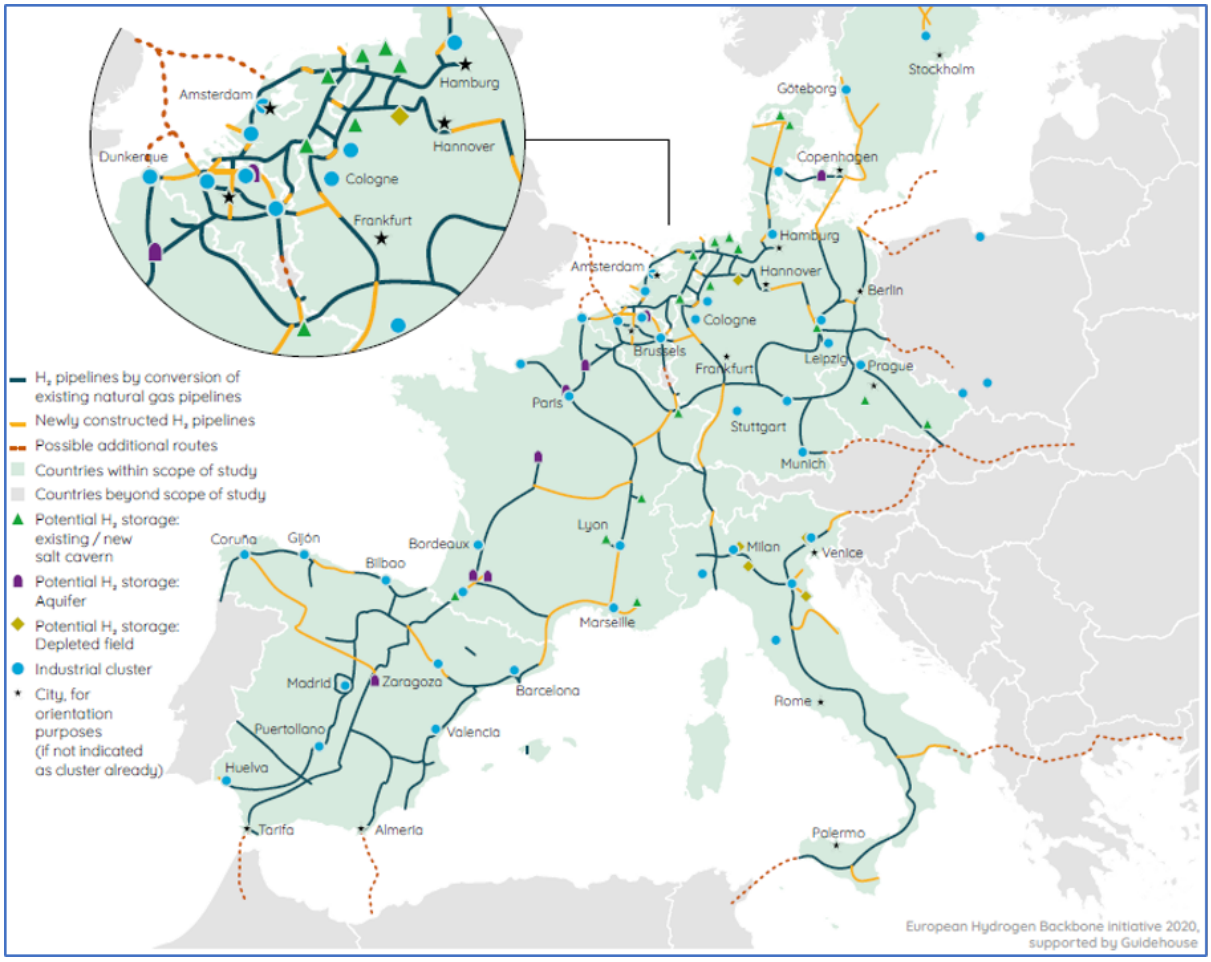
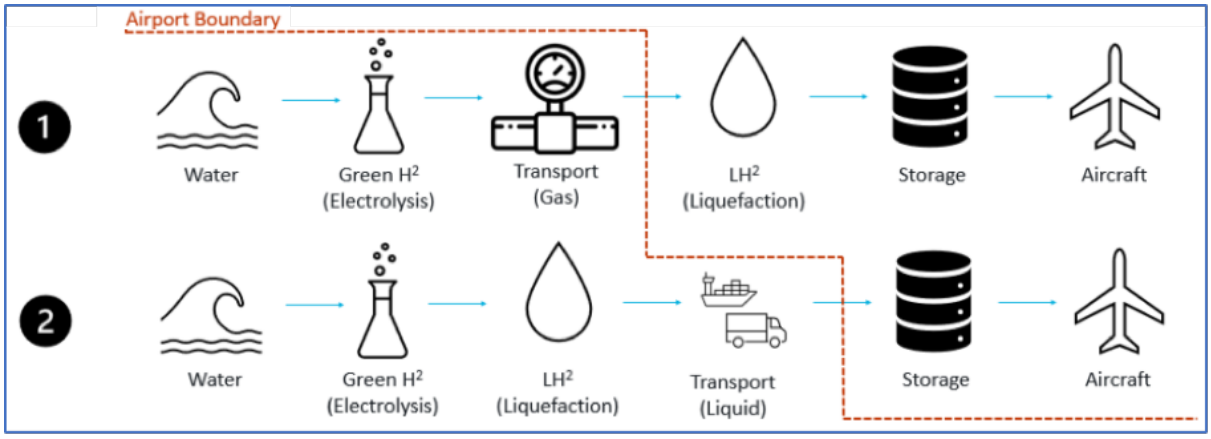


Figure 6 shows how hydrogen could be distributed to airports.

Figure 6: Options for distributing hydrogen to airports



Hydrogen can be transported as a gas through pipelines, in which case it will need to be liquefied at the airports before storage. Alternatively, it could be liquefied at source and transported, at 20K (-253°C) in ships, barges or, and particularly for smaller airports, trucks.

Wherever it is carried out, the energy requirements for liquefaction would be considerable, as liquefaction requires around one seventh of the energy ultimately stored in hydrogen fuel. By 2050, London Heathrow, the European airport projected to require the most hydrogen fuel, could have over 350,000 departing flights, 180,000 of them served by nearly 100 hydrogen-fuelled aircraft based. These would have an annual hydrogen demand of over 230,000 tonnes and liquefaction energy requirement of around 1,750 GWh per year.

Challenges: airport infrastructure

At airports, existing fuel farms for kerosene would need to coexist, for a while at least, with new cryogenically cooled ones for hydrogen fuel, and in some cases liquefaction facilities. This might be difficult or impossible at airports with are space-constrained. One issue is that liquid hydrogen fuel boils off at around 1% per day, but this could be manageable if airports held only a 2-3 day supply.

Four times as much fuel would need to be delivered to aircraft. This could be done in cryogenic bowsers, increasing airside traffic and, potentially, adding to congestion on the apron. The alternative, delivery through a hydrant system, would be disruptive during construction and technically challenging. At present, liquid hydrogen has not been shown to be piped more than around 300 metres, whereas the required distances at airports are likely to be several times further, requiring significant technology development and expense. In either case, there would be new safety issues associated with a highly flammable fuel and the risk of frostbite, although there is no technical reason why these cannot be successfully managed.

Challenges: airline and aircraft operations

The introduction of hydrogen-fuelled aircraft would also raise several challenges for airlines.

First, fleets would often need to be split, or more aircraft types operated, with implications for crew training and aircraft servicing and maintenance.

Second, it would be highly disruptive to operations if hydrogen fuel were not available at airports to which aircraft were diverted.

Third, existing aircraft have relatively homogeneous operational characteristics such as approach speed and rate of ascent or descent. If hydrogen-powered aircraft had different characteristics, then the effective of capacity of airports and airspace could be reduced.

Fourth, ground handling would require different equipment and procedures. If hydrogen-fuelled aircraft had to be handled remote from existing stands, this could be highly disruptive. Any increase in overall turnaround times could require more stands and more aircraft, affecting airport capacity and airlines' business models.

Challenges: legislation and policy issues

There is a wide range of European legislation and policy measures relevant to hydrogen aircraft, and significant support for hydrogen technology development through Joint Undertakings, but:

- Hydrogen does not form part of the aviation-related measures in the "Fit for 55" and "ReFuelEU" initiatives.
- The EU hydrogen strategy and RePowerEU do not specifically address aviation.

Europe accounts for only around 20% of global aviation and there is no market for hydrogen-fuelled aircraft if the EU alone has to pay for them. Peter noted that direct EU subsidies to a new aircraft type could be challenged as unfair by existing manufacturers.

Globally, the largest aviation markets will be the US and the rapidly growing China and India. In the US, aviation decarbonisation policy includes no support for the use of hydrogen-powered aircraft, and focuses strongly on incentives to produce and use SAFs. (There are also incentives to produce green hydrogen, but this has not been linked to aviation.) The international focus on aviation climate change mitigation is also currently on SAFs. Several other countries have major aviation strategies and initiatives, but none of them specifically focus on

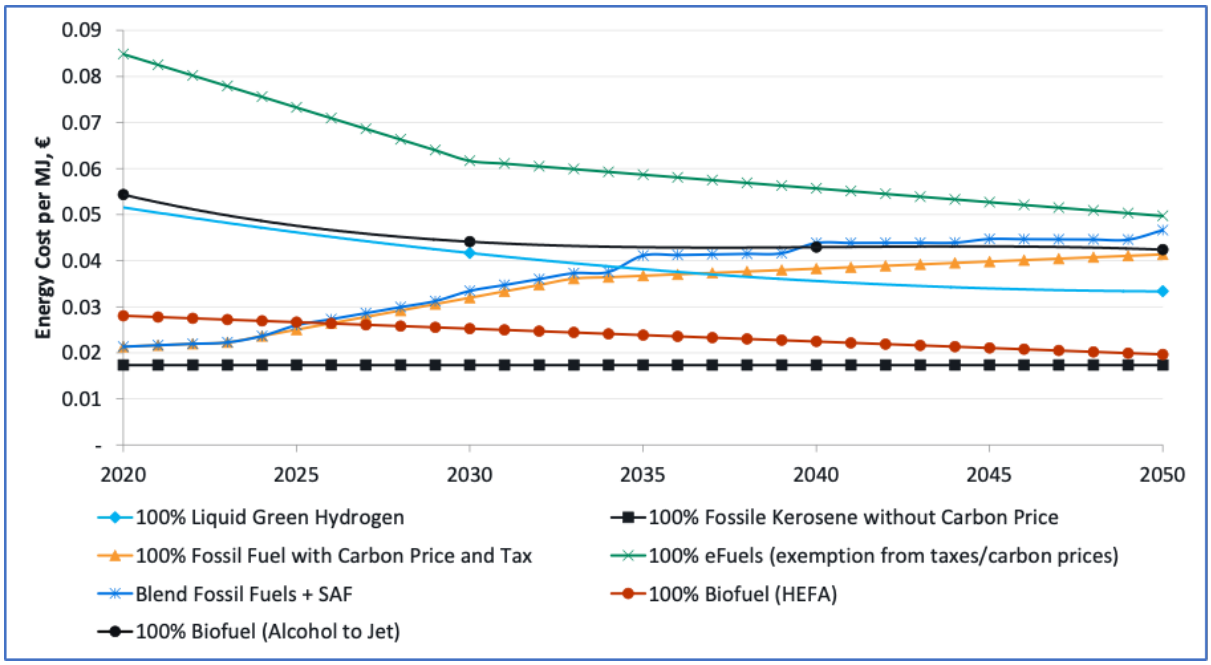
hydrogen. A 2022 International Civil Aviation Organization (ICAO) report on CO_2 emissions from aviation emissions reduction goals assumes that hydrogen will not have "any material impact until after 2050".

Costs

Figure 7 shows the assumed costs, in euros, per MJ of energy over time. On these assumptions, green hydrogen fuel (light blue line with diamond markers):

- is likely to become cheaper than 100% e-fuels; and
- may by 2035 be competitive with SAF or a SAF/fossil kerosene blend, but may be undercut by SAFs if the latter are financially supported in jurisdictions outside the EU (the 2022 US Inflation Reduction Act (IRA) includes tax credits to SAF); but
- is likely to remain more expensive than fossil kerosene (black) without a carbon price.

Figure 7: Expected price development of energy carriers



Sources: Deutscher Bundestag, Deutsche Energie-Agentur GmbH (dena), ICCT Working Paper 2022-14.

Peter noted that the institutional arrangements of the EU make it harder than in some other jurisdictions to "backslide" on legislation once it had been agreed.

Hydrogen-powered aircraft are only zero emissions if powered by green hydrogen produced by electrolysis using electricity either:

- from wind power, notably in northern Europe; or
- from solar power, notably in southern Europe and Africa.

Figure 8 shows the assumed onsite hydrogen supply costs across the study area[8]. While these will fall everywhere over time, they are consistently lowest in Africa and areas bordering the North and Baltic Seas, with higher costs in landlocked areas on the European mainland, including busy airports such as Geneva, Zurich, Munich and Vienna.

Figure 9 shows Europe's 50 busiest airports, the assumed four hydrogen production sites, and the rollout of hydrogen to the 50 airports by 2040 and all airports by 2050. This would be achieved by prioritising:

- airport size, starting with larger airports;
- traffic structure, starting with airports with a large proportion of short flights which could be served with tankering;
- "macro-logistics", or access to green electricity and petrochemical or steel industries; and
- "micro factors", such as lack of space constraints, or a strong commitment to further hydrogen use.

This scenario was seen as possible, but only with determination and suitable funding mechanisms.

[8] Source: Hamburg University of Technology (TUHH)

Figure 8: Production cost of hydrogen (€/kg 2020 prices)

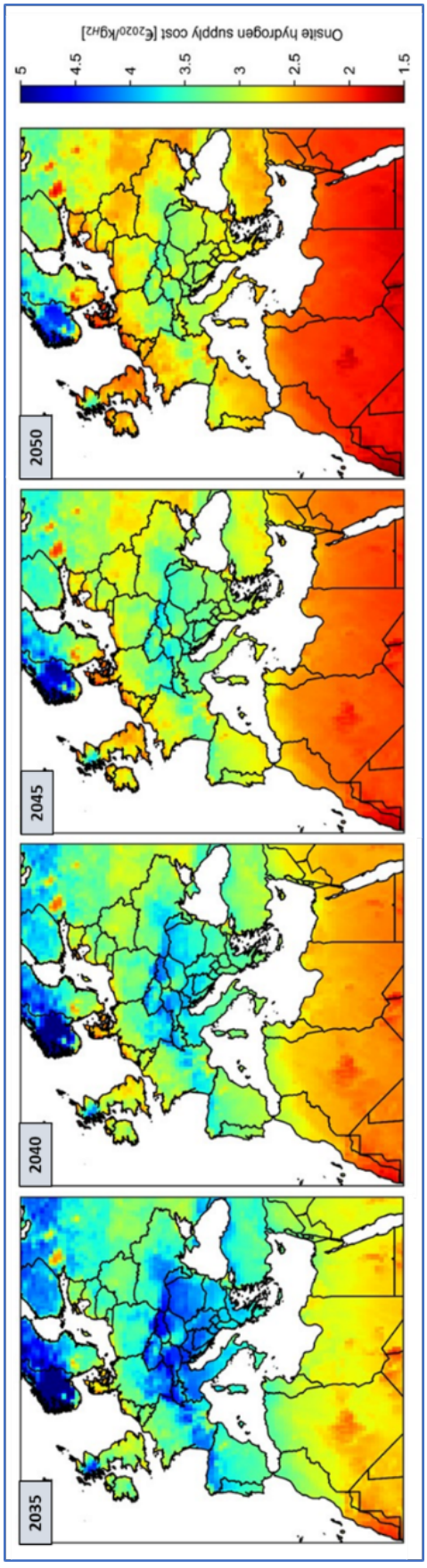


Figure 9: Airports, assumed production sites, and rollout

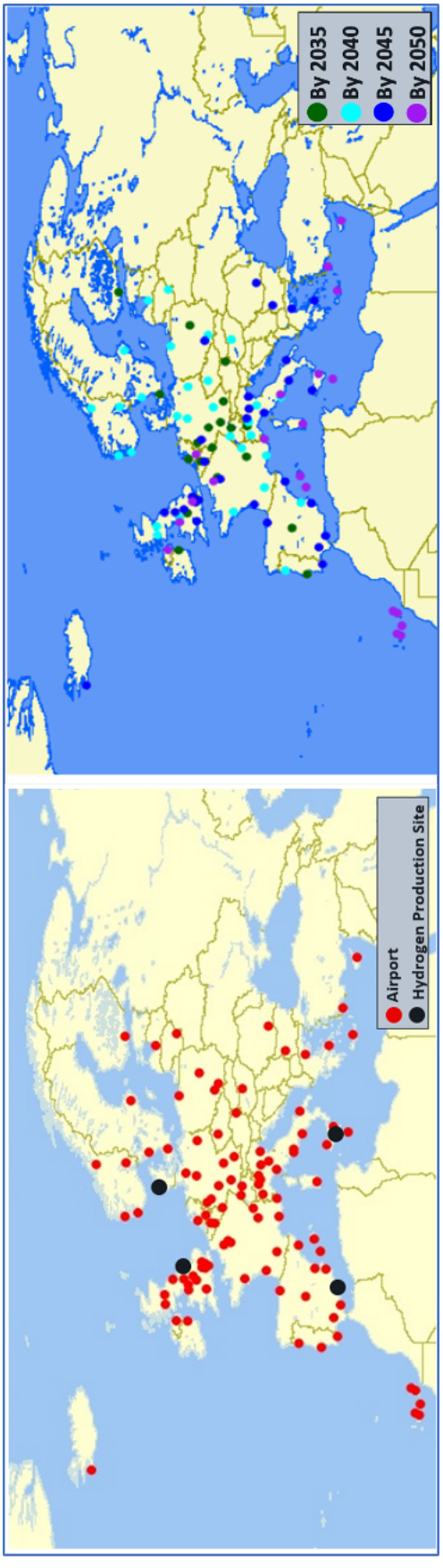


Figure 10 shows the estimated in-scope capital and operating expenditure (capex and opex) to 2050. Peter noted how capital expenditure would continue to rise for later developments, but this was out of scope.

Figure 10: In-scope capex and opex, 2025-2050

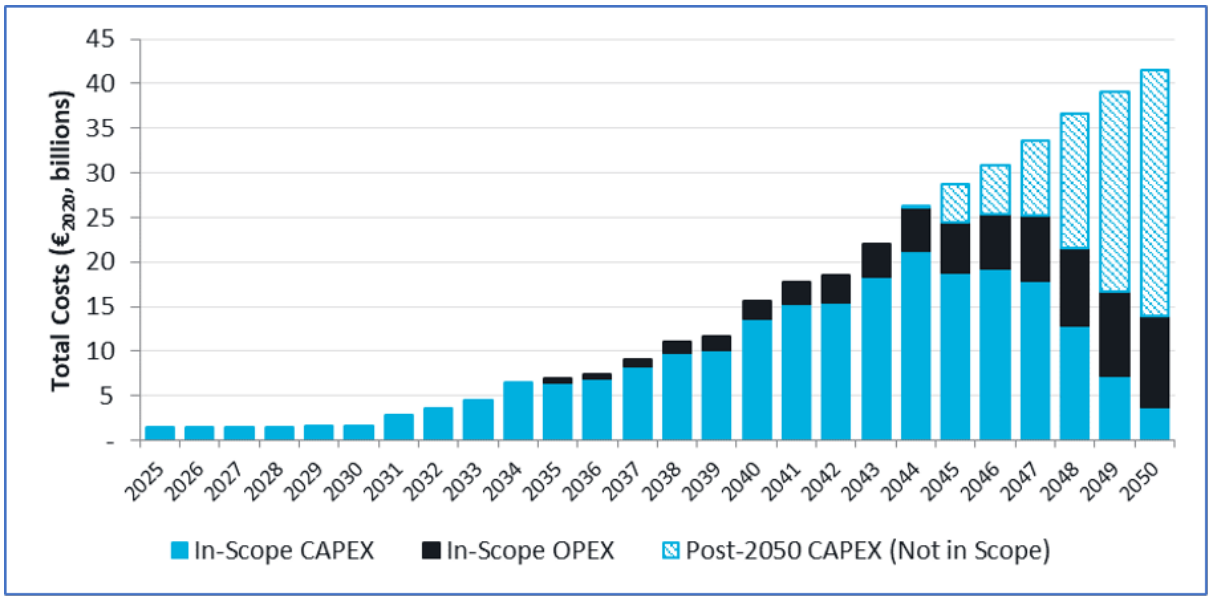


Figure 11 focuses on the in-scope capex and opex and shows importance of capex associated with hydrogen fuel production.

Figure 11: Cost by activity by year, 2025-2050

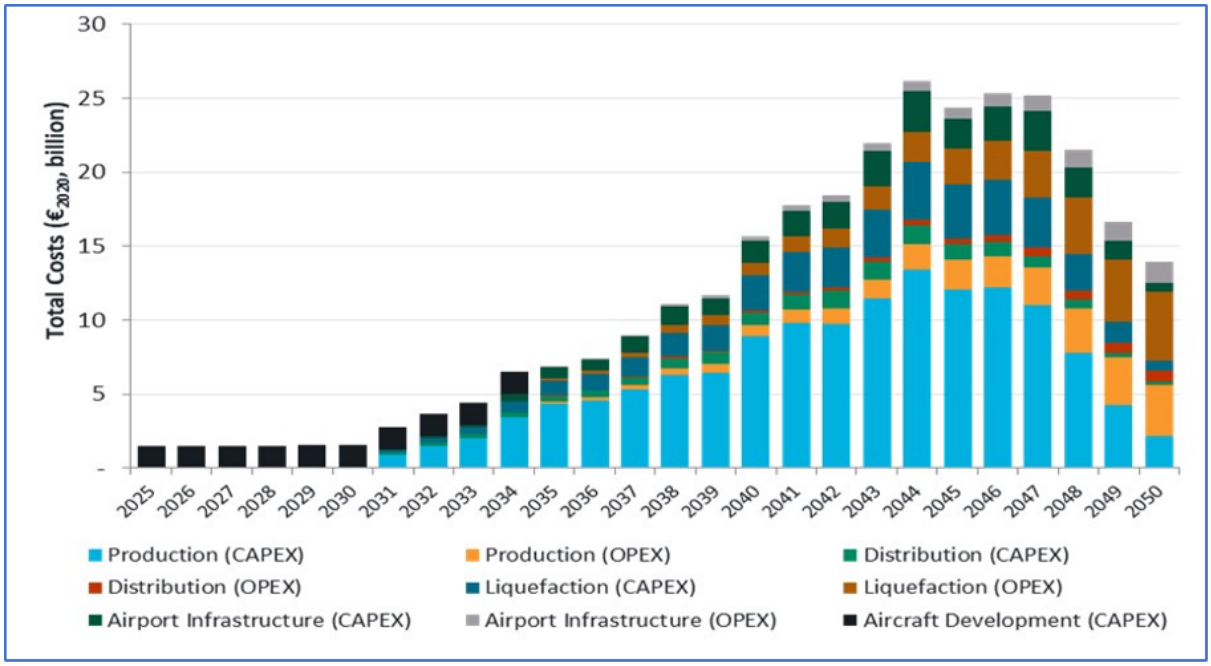
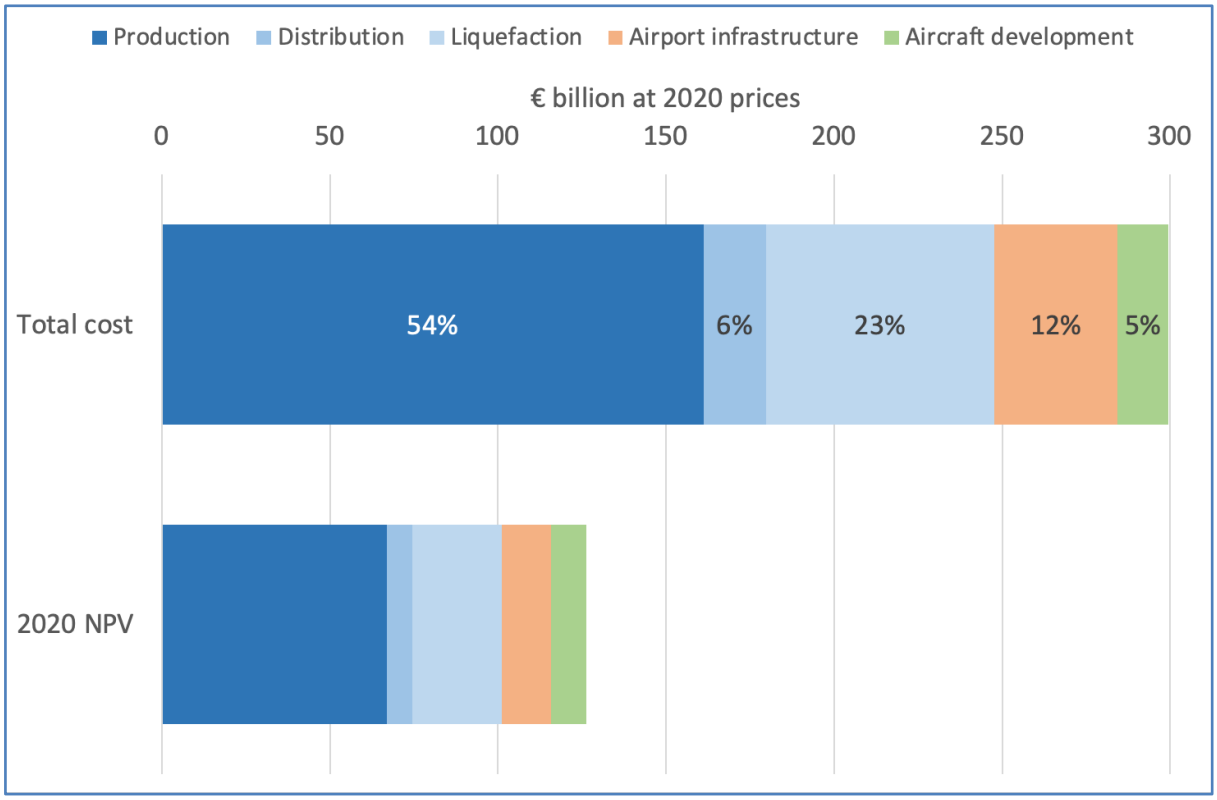


Figure 12 combines the capex and opex elements in Figure 11, showing the contribution of each activity to the total cost and to the Net Present Value (NPV) in 2020.

Figure 12: Total cost by activity, 2025-2050



Only 17% of the costs are associated with airport infrastructure and aircraft development, with the remaining 83% being related to the production, distribution and liquefaction of hydrogen fuel.

Conclusions

Peter concluded that the rollout of hydrogen aircraft faces many challenges. Within the delivery chain shown in Figure 12:

- **Production** of green hydrogen is perhaps the greatest challenge, and is unlikely to be achieved by the aviation industry on its own (see Figure 4), but needs to be part of a developing "hydrogen economy".
- **Distribution** of hydrogen requires a pipeline network and will again need to share costs with other industries.
- **Liquefaction** of hydrogen, which is specific to the aviation industry, is highly energy intensive and will be expensive.
- **Airport** infrastructure and operational processes face significant challenges which are likely to lead to disruption and significant costs.

- **Aircraft** development raises technical challenges which can be overcome, but significant investment is required and, with limited support outside Europe, the size of the global market is unclear.

In addition, there will be competition from:

- **fossil fuels**, which may be mitigated by carbon pricing and/or fuel taxes; and
- **SAFs**, which may remove/reduce incentives to move to hydrogen aircraft/fuel, are strongly supported by policy in Europe, and are the clear preference for aviation decarbonisation in the rest of world, particularly the US.

This can be summarised as high costs, estimated at €300 billion (2020 prices) in Europe by 2050. Peter posed the question "Is this an impossible barrier or a relatively minor cost well worth paying?"

Discussion

Peter Gordon asked if compression was an alternative to liquefaction. **Peter** said that, compressed to 700 bar, hydrogen holds only 5.6 MJ/litre and would require very strong, and hence very heavy, tanks which, unlike current aircraft fuel tanks, would have to be spherical or cylindrical. This approach would only be practicable on a small scale.

David Metz asked whether fuels such as ammonia could be used. **Peter** noted that ammonia (NH_3) would result in large NO_x emissions. More widely, all the options are harder than using SAF, but while SAF can be made from hydrogen, it requires an extra step to combine it with carbon extracted from atmospheric CO_2, so creating green SAF requires more processes and energy than creating green hydrogen.

Gregory Marchant asked to what extent the energy consumption of aircraft depended on how far they fly. **Peter** said that short haul aircraft consumed the equivalent of around 3 litres per 100 passenger kilometres, about half that of a car, so aircraft were as fuel-efficient as a car carrying two people. The difference was that some people fly in a few hours as far as they would drive or be driven in a year.

David Metz asked if there were better means of storing hydrogen, such as adsorption onto metals. **Peter** said that there may be other storage options, but these would involve more processes and would not remove the need to produce and distribute hydrogen. More widely, any approach would require long-term political and policy stability, which might not emerge where there could be major swings in government policy, such as the US.

David Parish asked whether hydrogen power could begin with smaller aircraft and gradually be extended to larger ones. **Peter** said that this is the approach being adopted by ZeroAvia, which was developing hydrogen-electric fuel cells powering electric motors, replacing turboprop engines[9].

Alex MacDonald asked if the technology would only work for short haul flights. What about ultra-long haul, such as London to Sydney? **Peter** said that London to Singapore (nearly 7,000 nautical miles or 11,000 kilometres) might be possible, but not for a long time, potentially around 2070.

Peter Gordon said that the main problems with SAF seemed to be the feedstock and the path. Will there be improvements? **Peter** said that there was not enough feedstock. **Peter G** asked if organisms such as algae could be used? **Peter** said that the first step in this approach achieves the objective of extracting CO_2 from the atmosphere: once this was done, there might be better next steps than the complexity of creating and using hydrogen fuel. In addition, if SAF production required land, this could not be used either for other crops or for reforestation, removing the opportunity to extract CO_2 from the atmosphere as food, plants or wood. It was currently estimated that it would be cost-effective to extract CO_2 from the atmosphere if the cost could be brought below $600/tonne.

Dick Dunmore noted that people did not realise how effective kerosene was: it can be a safe and usable liquid at temperatures from below -60°C to above +60°C, can be stored at ambient air pressure, evaporates slowly, does not easily catch fire, stores around 32MJ per litre and 40MJ per kilogramme, and disappears as it is used. **Peter** added that it is also transportable by pipeline

[9] https://zeroavia.com

or tanker and already available "everywhere": unlike other transport modes, aviation is standardised globally. SAF, while of different origin, still shared all these beneficial characteristics. **Gregory Marchant** asked whether one could combine kerosene with carbon capture and storage (CCS). **Peter** said that CCS is not proven.

Dick Dunmore also asked whether making charcoal could be industrialised to reduce CO_2 to carbon, which could be reburied.

David Metz wondered whether hydrogen fuels could be prototyped on military aircraft. **Peter** said that this was not the focus of Steer's study, and in any case the military are generally unwilling to share too much information. The military are typically driven by features such as performance, durability or versatility.

Peter White asked about standardisation of fuel taxation. **Peter** said that this had been achieved, but at a harmonised rate of zero as a global default. The EU had created a fuel tax, carbon pricing, and a mandate to use a growing proportion of SAF. In addition, the EU-UK Trade and Cooperation Agreement (TCA) includes a chapter on aviation, effectively an Air Services Agreement, which allows fuel taxation for flights within the EU+UK.

Tim Elliott asked about the one-seventh loss in hydrogen liquefaction. Peter clarified that this was not a loss of hydrogen, but rather that the energy required to liquefy hydrogen was one-seventh the energy it stored. **Tim** concluded that the question remained "What is the boundary for the project, and is the only relevant aim the remove of reduction of atmospheric CO_2? **Peter** agreed.

Gregory Marchant closed the meeting by saying that the talk had been an eye-opener and had taken his breath away. Transport always seemed to have unexpected complications.

Report by Dick Dunmore

Dynamic Clustering and Transport Appraisal

Daniel Hanson, NERA and
Sandy Fong, New Zealand Transport Agency

Online

27 March 2024

Introduction

The New Zealand Transport Agency (NZTA)

Sandy Fong explained how the NZTA research programme team generates, scopes, commissions, manages and ultimately publishes the projects on their website[10].

NZTA currently has around 50 research projects at any one time, all applied research with one or more "end user" stakeholders.

NZTA has published:

- since 1991, over 700 research reports;
- since the mid-2000s, 2-3 page "summary stories" for the less technical reader; and
- since 2021, shorter "research notes" which are mainly literature reviews.

Sandy ended by listing several research reports which might be relevant, or if interest, to TEG members[11], one of which would be the main subject of the meeting.

NZTA Research Report 680 "Dynamic Clustering and Transport Appraisal"

Daniel Hanson is a Managing Director at NERA with prior experience at PwC. His talk focused on this 2021 report on an area in which, with 10-12 years' experience, he suggested he was a relative newcomer. His experience includes:

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[10] https://www.nzta.govt.nz/resources/research
[11] Research Reports 661, 670, 671, 676, 680, 681, 684, 686, 698, 699, 700 and 702

- leading the economics advice to the Airports Commission[12];
- similar Wider Economic Impact appraisals of the A303, the Lower Thames Crossing, and the A14, all of which raised issues beyond the parameters of standard Transport analysis guidance (TAG) at the time;
- working for the Department of Transport (DfT) on reconciling the GVA and welfare impacts of transport interventions; and
- expert panels including the Hansford Review of third party investment in rail infrastructure, Road Investment Strategy (RIS) 2 and 3, and the economic advisory panel to High Speed 2.

He and his colleagues had seen NZTA's tender for research on dynamic clustering and were delighted to have been appointed in a highly competitive tender. He would summarise highlights of the resulting report and then invite comment and discussion.

Research objectives, approach and Research Questions

As background, transport projects may not only improve transport links but also transform an area, but NZTA's economic evaluation approach did not capture dynamic clustering impacts, which can be central to a project's business case.

NERA's task was to develop a framework assessing:

- whether, the extent to which, and how transport interventions triggered dynamic clustering; and
- how to analyse the economic impacts of dynamic clustering.

The project consisted of three phases:

- literature review;
- methodology report; and
- case studies in New Zealand and the UK.

Table 1 summarises the Research Questions to be addressed.

[12] https://transecongroup.org/wp-content/uploads/journal/Transport_Economist_42-3.pdf

Table 1: Research Questions

1	What do we mean by terms like **dynamic clustering, agglomeration, land-use change**?
2	How, when and under what conditions do **agglomeration externalities (positive and negative)** occur?
3	What **micro-processes occur** in the lead-up to (and after) agglomeration economies, and what **feedback loops** exist between processes?
4	How do **transport projects affect micro-processes?**
5	How can different models **trace the cause and effect** from transport projects, to micro-processes, to agglomeration economies?
6	What approaches should be incorporated into **transport appraisal guidance**?
7	What would a **recommended approach** look like using a case study?
8	What are productive areas for **future research**?

Dynamic clustering (Research Question 1)

Clustering of activity is when people and/or businesses are made closer to each other (density and/or concentration).

The study adopted the definition that

Dynamic clustering is "The process of density increasing through time due to relocation or reconfiguration".

Dynamic clustering can cause agglomeration through the effects of changes in density. The most prominent benefit is increased productivity, but there are also costs, such as increased congestion.

Insights from the literature review

The literature review provided insights into definitions, processes and analytical techniques. While difficult to summarise, key points were that:

- understanding decision-making by firms, individuals and landowners is crucial;

- sharing, matching and learning all drive productivity gains, but the relative importance, timings, spatial parameters and feedback mechanisms are not well understood;
- analysis of the property market can be extremely important but only if it is done properly (in particular, avoiding double-counting), both conceptually and empirically;
- the whole area, particularly robustly quantifying impacts, is extremely challenging; and
- there is a need to be abundantly clear and practical, rather than formulaic or handle-turning use of standard models, even on "simple" appraisals.

He followed with several slides illustrating these points.

Static impacts

Figure 1 provides a checklist of what Daniel referred to as the "static impacts":

- Plain shaded impacts are always considered.
- Unshaded impacts may not be included but might be in future.
- Hatched shading impacts are more frequently looked at when doing a dynamic project appraisal.

He noted that:

- Direct user benefits' welfare and output impacts are distinguished, making use of the "Squaring the Circle" project that Daniel had carried out for the DfT. This shows how, classically, journey time savings all have a welfare impact, but there is no output impact for leisure trips.
- Labour market impacts are interesting but complex.
- Consumption is not well understood.

Dynamic impacts

Figure 2 is a similar checklist showing how impacts can change in a dynamic world. One important thing to note is that many of these impacts can be in either direction. This underlines the need for transparency, not only in logic maps to understand what is likely to happen, but also in how it is modelled.

Figure 1: Static impact summaries

Impacts		Measured through	Welfare	Output
Direct user benefits	Business trips	Savings in travel time, together with the value of time.	✓	✓
	Leisure trips		✓	–
	Commuters		✓	✓
Agglomeration effects	Agglomeration	Changes in access to economic mass caused by changes in travel time, together with agglomeration elasticities.	✓	✓
Market structure effects	Imperfect competition	Mark-ups on the direct user benefits referred to above that accrue to business. Rationalised by how the price-cost margin in imperfectly competitive markets magnifies the impact of reductions in cost on price and output.	✓	✓
	Increase in competition	Increase in competition reduces deadweight losses.	✓	✓
Labour market effects	Tax wedge	The tax on increased income/output caused by people working more as a result of lower commuting costs. Value depends on elasticity of labour supply and assumes that people are perfectly compensated for working instead of taking more leisure.	✓	✓
	Increase in labour supply	The private value to people from working more as a result of lower commuting costs. Value depends on elasticity of labour supply and assumes that people earn more than they forego in lost utility.	✓	✓ (*)
	Move to more/less productive jobs	The tax on increased income/output caused by people being able to access more productive jobs. Like the tax wedge effect, the analysis assumes no private benefit (ie, benefits from better jobs are offset by increased cost of travel).	✓	✓
	Move to more productive jobs	The above but when private benefits do accrue (eg, when labour markets do not price labour perfectly and/or when there is structural unemployment).	✓	✓ (*)
	Increase in competition	Firms' monopsony power (as buyers of labour) decreases. Workers' monopoly power (as suppliers of labour) decreases.	✓	✓
Consumption	Amenity benefits	No proposed method, may be possible using hedonic analysis.	–	–
Environmental effects	Marginal external cost	Carbon, congestion, health, air quality.	✓	–

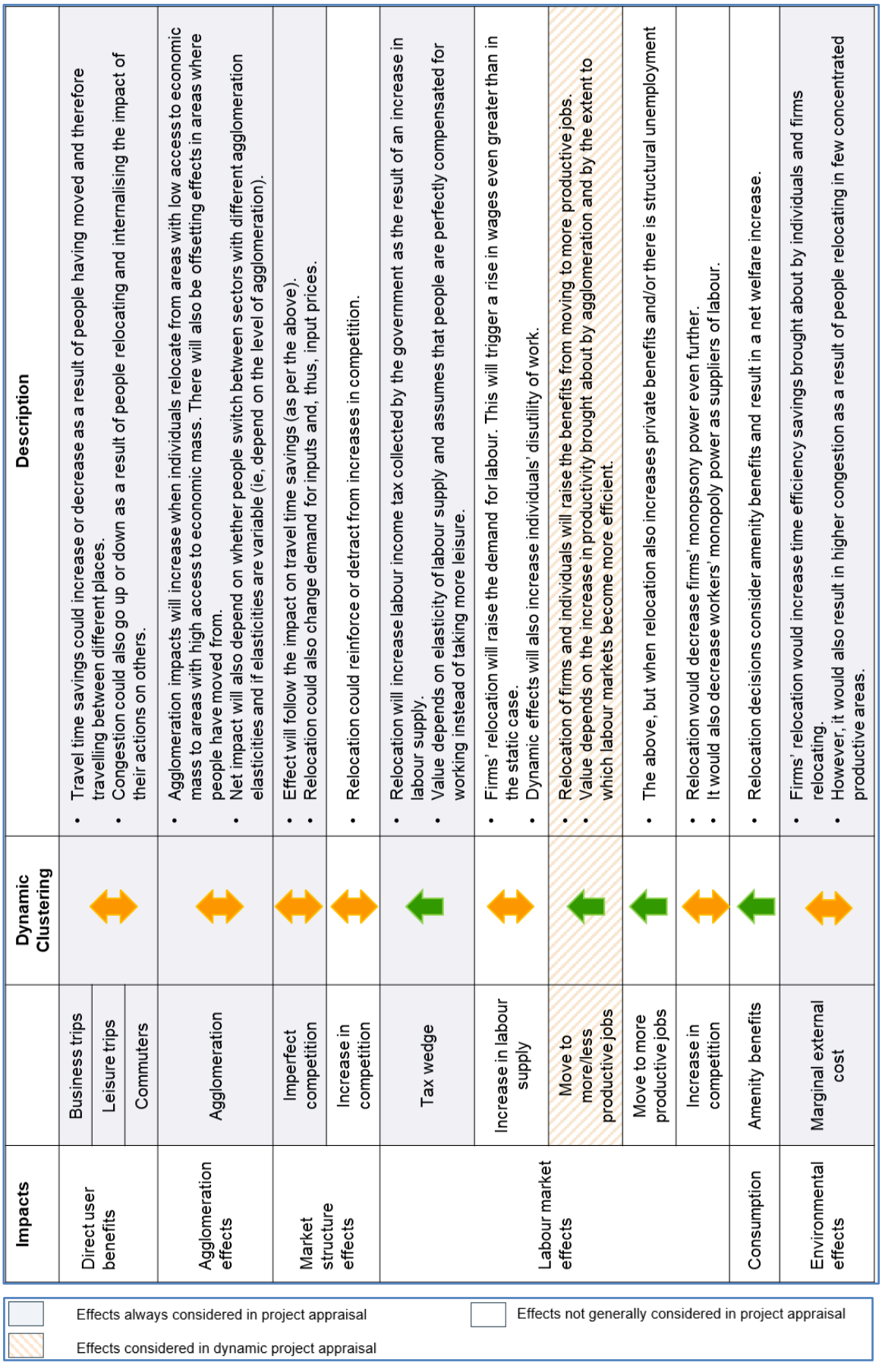
Effects always considered in project appraisal

Effects not generally considered in project appraisal

Effects considered in dynamic project appraisal

(*) Output effects are larger than welfare effects

Figure 2: Dynamic impact summaries



Timing, feedback loops and additionality

Figure 3 summarises the likely timing of impacts, what feedback loops might exist, and what might be truly additional.

On agglomeration, for example, the standard approach is to calculate the change in access to economic mass and to apply an agglomeration elasticity, but what is less well understood is when and how the impacts might materialise. For example, sharing and matching effects might come into play relatively quickly, but learning effects take much longer, so some of the modelling effects should not be assumed to materialise immediately, and a reasonable time profile should be adopted. However, some early effects may arise from anticipation of later ones, such as when land values rise because of the expectation of future changes.

Logic maps

Figure 4 is an example of the type of logic map developed in the study. Daniel emphasised the need to get away from "handle-turning" and to have a clear model of what drove impacts:

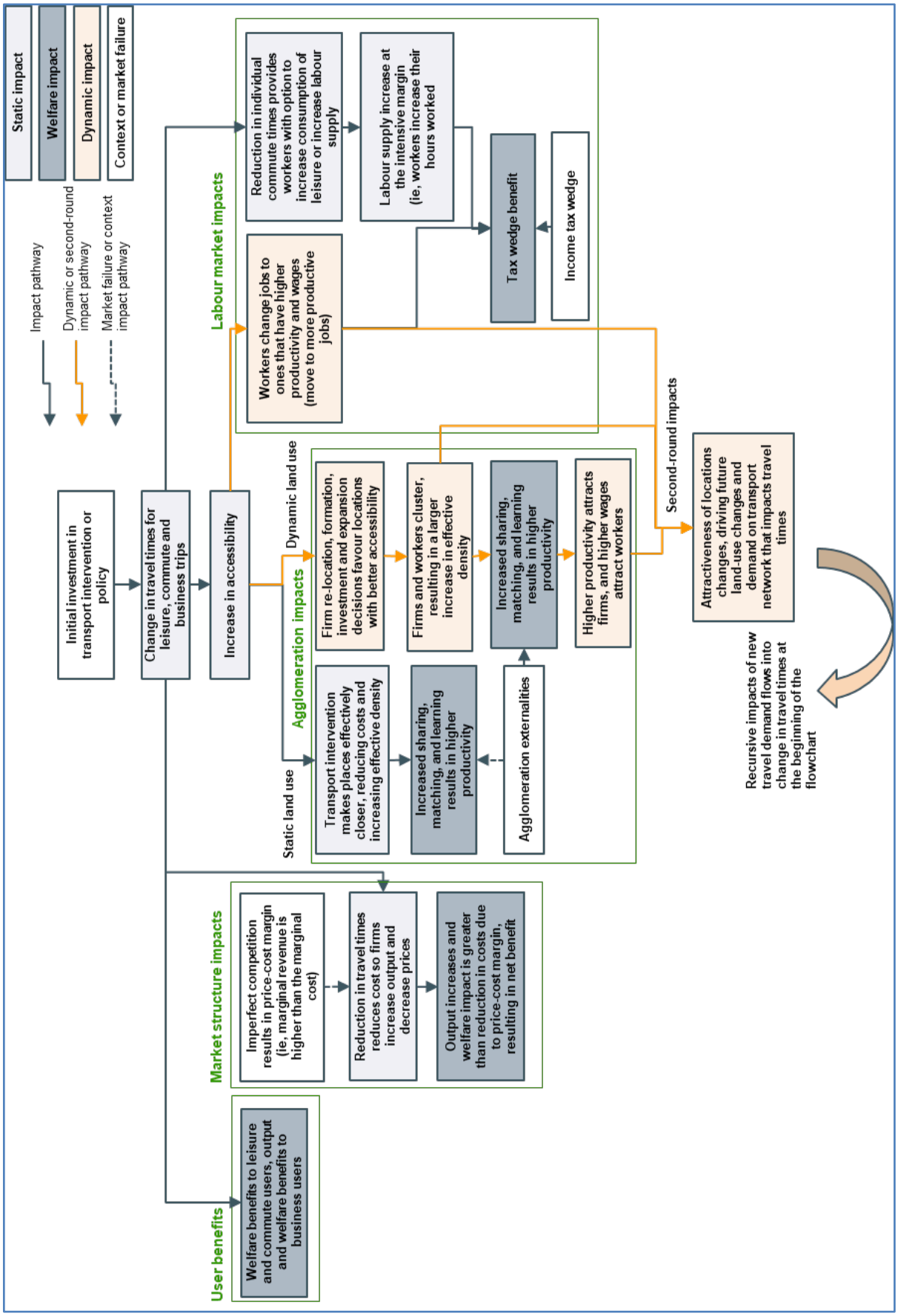
- Unshaded areas refer to the context or market failures: in this case the initial investment is part of the context, but market failures include imperfect competition, agglomeration externalities and the income tax wedge.
- Dark grey areas are welfare impacts.
- Orange areas are more dynamic impacts.

From the top, the map flows from the initial investment in a transport intervention or policy, through changed travel times, and then on the left into user benefits, and so on. In addition to the impact summaries discussed above, in this example there are also impacts on the property market.

Figure 3: Timing, feedback loops and additionality summaries

Impacts		Timing	Feedback Loops	Additionality
Direct user benefits	Business trips	Direct user benefits may arise relatively quickly, together with costs and time reductions.	Negative feedback loop arising from greater congestion and higher intensity in land use.	Rule of half applies to new trips due to transport intervention. Understanding the reason behind new benefits would be crucial to avoid double counting.
	Leisure trips			
	Commuters	Time for higher attractiveness of land use depends on the supply of land.		
Agglomeration effects	Agglomeration	Sharing and matching mechanisms of agglomeration may generate quicker benefits than learning (after 10 years).	Positive feedback. The change in attractiveness of locations due to higher productivity may result in yet more agglomeration.	Productivity increases have historically proven to be additional with respect to direct user benefits.
		Dynamic agglomeration benefits may take even longer to materialise.		
Market structure effects	Imperfect competition	The timing of first order impacts is assumed to occur contextually to a reduction in costs.	Further increase in competition due to an increased attractiveness of a location is plausible, although not expected to be large.	Impacts can be additional but magnitudes are unlikely to be large.
	Increase in competition	The timing of place attractiveness evolves more gradually over time and depends on the elasticity of labour supply.		
Labour market effects	Tax wedge	Changes in labour supply (and related tax and private benefits) are not immediate because of labour market frictions.	Positive feedback. The change in attractiveness of locations due to higher productivity may result in a further increase in labour supply.	The move to more productive jobs in a different location implies a change to travel behaviour, which should be reflected in modelling of direct benefits to avoid mis-counting.
	Increase in labour supply			
	Move to more productive jobs	Dynamic labour market benefits may take even longer to materialise.		
	Structural unemployment	Reduction in structural unemployment and monopsony power following a transport intervention will not be immediate.	Unlikely positive feedback. Structural unemployment benefits would need to affect a large proportion of the population to trigger feedback loops.	Benefits from this type of impact would be additional and would also include health benefits resulting from people brought into the labour force.
	Increase in competition	Dynamic labour market benefits may take even longer to materialise.		
Love of variety	Benefits from access to variety	Impacts likely to materialise immediately.	Both positive and negative feedback loops may occur.	Impacts likely to be additional but challenging to quantify.
Environmental effects	Marginal external cost	Environmental benefits from mode switch would be quickly implemented, while other health benefits triggered by lower congestion and emissions would take more time to implement.	Positive or negative feedback loops possible. Congestion may reduce place attractiveness, or perhaps increased investment in amenities drives positive feedback loops.	Benefits from this type of impact would be additional as long as they are modelled to reflect the same state of the world implied by other wider economic impact models.

Figure 4: Logic maps



Case studies

Daniel noted that the frameworks could have been applied (ex-ante) to a live and forward-looking appraisal process or (ex post) in a manner more like an evaluation. The case studies were based on something of a hybrid:

- providing access to the original appraisal analysis;
- enabling discussions with those involved in the development of the business and economic cases; and
- making it possible to identify what would have been done differently if the frameworks set out above had been applied.

This choice of approach was intended to avoid undue controversy that could have been caused by applying it to projects being appraised at the time, such as High Speed 2 or East West Rail. The two chosen were:

- the Waterview Tunnel on Auckland's Western Ring Route; and
- the Northern Line Extension in London.

The Northern Line Extension linked the pre-existing line to a new development, and was a good example of how a land development and a transport project would not have happened without each other[13].

Figure 5 shows the impact summary of the Northern Line Extension, following broadly the framework of direct user impacts in Figure 1, but adding whether each impact was quantified in the Economic Case.

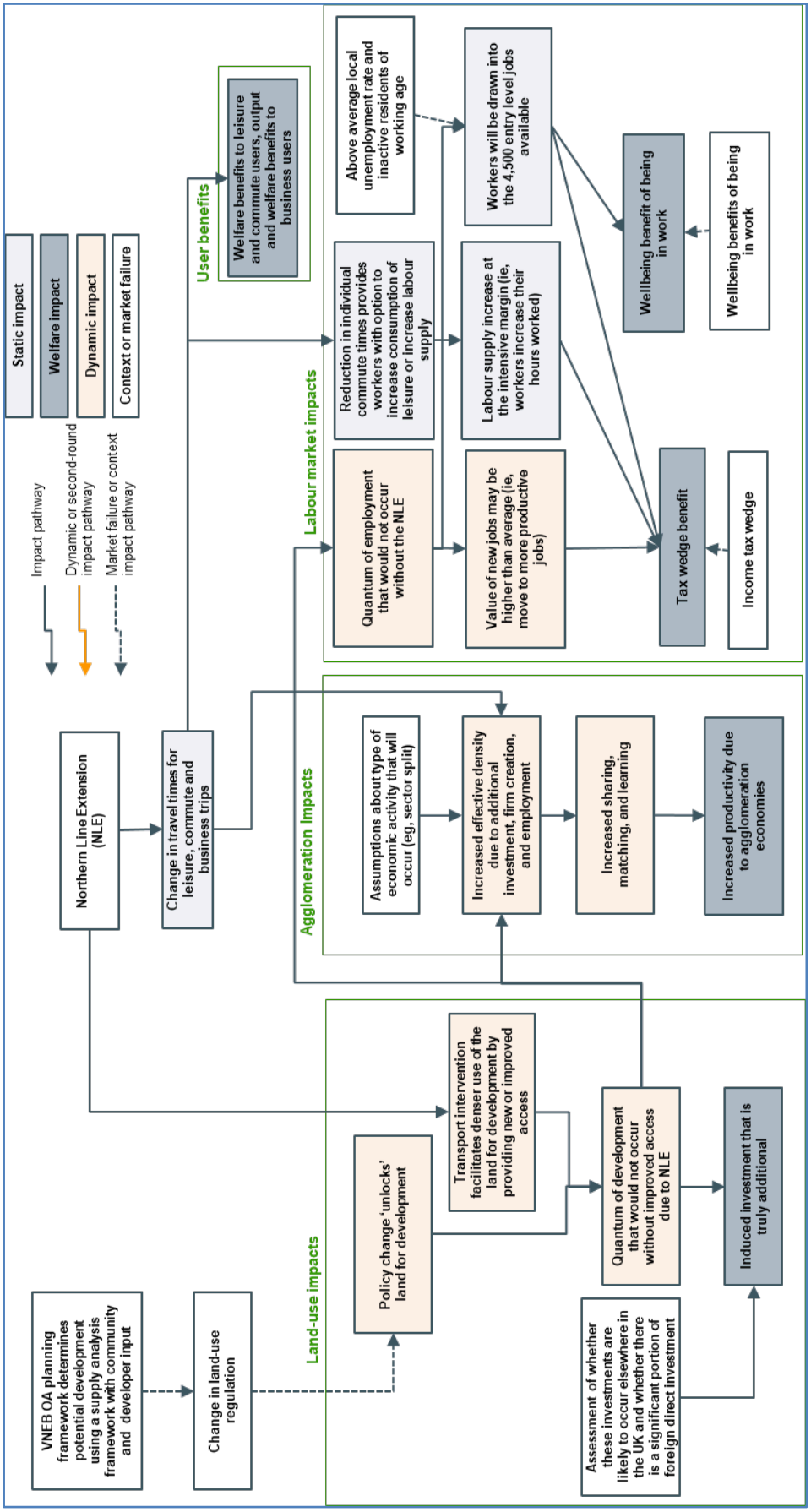
Figure 6 shows how the generic impact logic map in Figure 4 was tailored for the Northern Line Extension case study, in particular to focus much more on land use impacts (added, on the left) than user benefits (moved to the right). He noted that Transport for London (TfL) colleagues had found the framework useful, and hoped that NZTA and peer reviewers had done so, too.

[13] TEG's November 2023 meeting discussed a similar case, the Thamesmead & Beckton Riverside PTP Economic Appraisal, where it was clear that a land use change would not take place without a transport intervention.

Figure 5: Case studies: Northern Line extension impact summary

Impacts		Rationale	Welfare Impact	Quantified in Economic Case?
Direct User benefits	Business trips	NLE will reduce journey times for existing rail and road users and welfare benefits of new trips can be estimated using the rule of half	✓	✓
	Leisure trips	NLE will reduce crowding on the wider network and the benefits can be measured in terms of journey times savings and/or £pounds	✓	✓
	Commuters		✓	✓
Agglomeration effects	Agglomeration	NLE will make places effectively closer resulting in higher effective density and agglomeration economies Greater development in the VNEB OA will occur as a result of the NLE and this also increases effective density and agglomeration economies	✓	✓
Market structure effects	Imperfect competition	Some output increase due to business travel time saving in imperfectly competitive markets could be expected but likely small	✓	No, this impact is likely to be small
	Increase in competition	No strong reason to suspect increased competition in product markets	✗	N/A
Labour market effects	Labour supply – tax wedge	Around 5,300 jobs created in the VNEB OA will be low skilled or entry level and these could be filled by the unemployed people or economically inactive people in nearby wards	✓	This impact is not assessed because it is difficult to predict with certainty
	Labour supply – private benefit	If unemployed people or economically inactive people enter the labour force they would increase their income and likely their wellbeing	✓	This impact is assessed qualitatively
	Move to more productive jobs – tax wedge	The new jobs created in the VNEB OA are likely to be similar in output per worker to the average output of jobs in Inner London i.e. above average. This implies a movement away from lower output jobs to fill these new role – a move to more productive jobs.	✓	✓
	Move to more productive jobs – private benefit	If workers move to more productive jobs with commensurate higher salaries, they are likely to be better off	✓	This impact is not widely accepted in appraisal guidance
	Increase in competition	The large increase in jobs in the London CAZ will likely have effects on the wider job market, increasing competition and potentially requiring firms to bid up wages	✓	This impact is not assessed because it is difficult to predict with certainty
Environmental effects	Marginal External Cost	Reduction in road journeys would lower emissions	✓	✓

Figure 6: Case studies: Northern Line extension logic map



Is dynamic clustering truly additional?

Table 2 provides an overview of when dynamic clustering is truly additional. It is tempting, but not always realistic, to assume that this is the case, particularly when there may be offsetting effects in the areas from which there has been relocation.

Table 2: When is dynamic clustering truly additional?

1	**Potential increases in user benefits**, although this will depend on congestion, and there may be offsets elsewhere.
2	**Increases in agglomeration economies that are not fully offset elsewhere**, such as due to varying productivity, effective density, or agglomeration elasticities.
3	**Increased employment**, unless the labour market somehow functions with third-degree price discrimination, it seems plausible there will generally be a net private benefit, contrary to the approach in much existing guidance.
4	**Moves to more productive jobs and businesses**, which again are not fully offset elsewhere. This will be particularly additional if we see the clustering of businesses that might not otherwise have existed at all or if the businesses might otherwise have developed in another country.
5	**Imperfect/increases in competition** could act as a brake on additionality because of how it reduces the price-cost margin in output markets. However, if it boosts wages in the labour market, by reducing monopsony power of employers, then it could magnify the employment impacts set out in 3 and 4 above.
6	**Increased land supply**, which can be considered as an increase in productivity in much the same way as an increase in agglomeration economies. Whether it is net positive to GDP or welfare is, however, unclear. One could argue that the reduction in land prices that go with an increase in land supply will reduce GDP and welfare (depending on who owns the land).
7	**Distributional impacts**: if clustering has the impact of displacing economic activity from relatively affluent to relatively disadvantaged areas, then this could have a positive welfare impact even if the impact on national gross value added (GVA) is neutral.

Modelling dynamic clustering (Research Question 5)

Daniel found it useful to cluster modelling approaches into four main families, each with distinct pros and cons:

- Spatial computable general equilibrium model (S-CGE)
- Land Use Transport Interaction (LUTI) + wider economic impacts (WEIs)
- Induced demand techniques, sometimes referred to as "The Bates approach"
- Ad hoc analysis such as econometrics and surveys

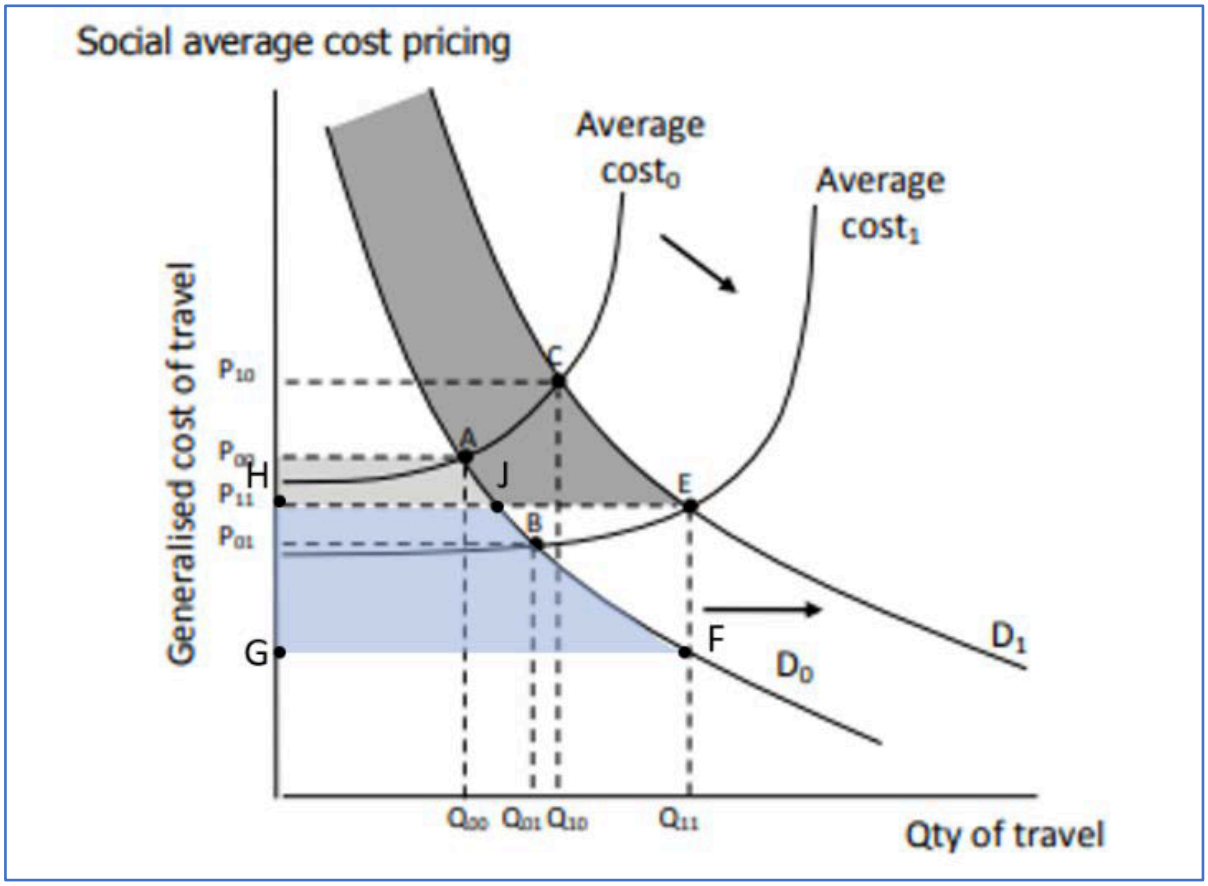
He highlighted that they are not always mutually exclusive: for example, his appraisal work on the Lower Thames Crossing used an S-CGE, but used bespoke econometrics to inform some of the parameters of the S-CGE model. Similarly, in the UK, LUTI and WEI approach has been deployed more frequently than S-CGE, but opinions differ on how transparent and robust these models are, and they have been used in conjunction with induced demand techniques to allow the results of two approaches to be compared.

Consumer surplus when supply and demand curves shift

Figure 7 shows the approach to induced demand, using a chart by New Zealand Institute of Economic Research (NZIER). At initial equilibrium, demand curve D_0 meets Average $cost_0$ at point A, but a scheme may lower the cost curve to Average $cost_1$, moving demand to B, and the "rule of a half" would focus on the triangle under AB. However, in a dynamic situation, the demand curve will also move to $Demand_1$ and demand will end at E.

The welfare impact is the dark shaded areas between the two demand curves above E. This area is difficult to calculate, but under certain conditions and assumptions it can be shown to be the same as the two other shaded areas bounded by $AP_{oo}GF$.

Figure 7: Consumer surplus when supply and demand shift



The methodology funnel

Figure 8 shows a suggested "methodological funnel" to help analysts and decision-makers identify the best practical approach to modelling.

First is a sense check of whether dynamic clustering is likely to be important or even material, which will not always be the case.

Second is identification of which mechanisms of dynamic clustering (see Figures 4 and 6) are likely to be important, and over what timescales.

Third is identifying which market failures and associated economic benefits should be measured. For example, land use regulation will not always be important.

Fourth, the approach will inevitably be constrained by what data and modelling tools are available, and decisions may be needed on what additional investment in data or models would be proportionate and cost-effective.

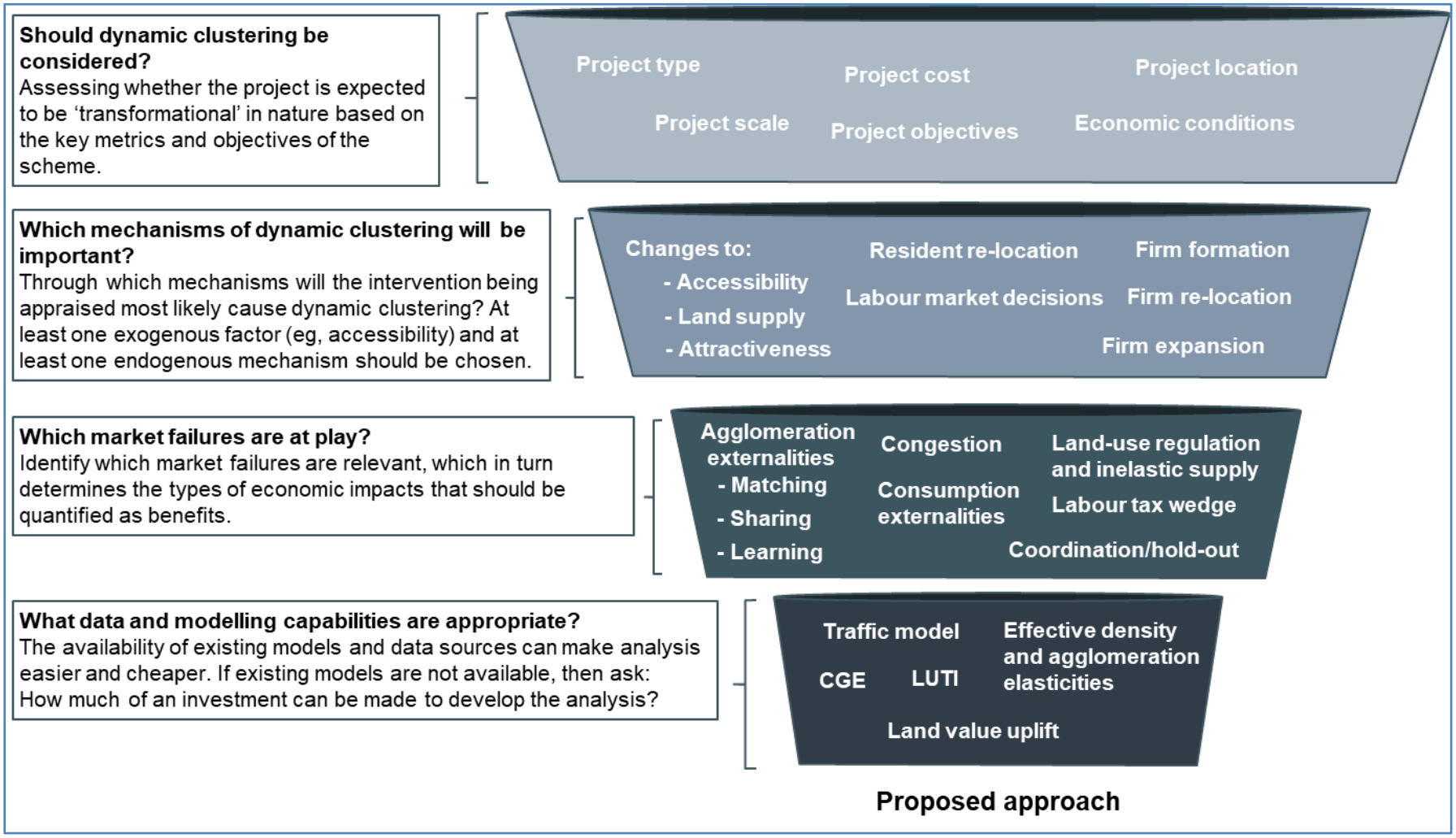


Figure 8: The methodology funnel

Areas for future research

Table 3 summarises the suggested areas for further work.

Table 3: Areas for future research

1	**Apply the framework on a "live" project "ex ante".** This could be at a high level and semi-illustrative basis, or on a much more detailed and quantitative basis.
2	**Develop the use of S-CGE models.** Simple or stripped-down versions could sense-check fuller models to help users to test and explain their results. The models could better analyse and capture individuals' and businesses' location choices, and have more granular analysis of land use.
3	**Refine approaches to LUTI modelling.** The aim would be to increase their transparency and the extent to which they are founded on sound economics and context-specific narratives and evidence.
4	**Develop the induced demand approach to benefits estimation.** It could be evaluated against a robust WEI framework approach.
5	**Gain a deeper understanding of labour markets.** Issues include: where increased labour supply generates truly additional welfare; the elasticity of labour supply; the impact of employment on wellbeing and opportunities; and the value of leisure and other time not in employment.
6	**Gain a fuller understanding of the magnitude of the relevant elasticities of land supply.** This elasticity parameter was identified as a key determinant of land and property prices, and the extent of dynamic clustering depends on whether more intensive land use is possible.
7	**Do further research on locational choice models.** Better models of how location choices are made by firms and individuals or households would improve how these decisions are analysed in LUTI or S-CGE models or ad hoc.
8	**Do further analysis of consumption amenity benefits.** These may provide welfare benefits additional to the welfare benefits generated from production externalities.

Conclusions

Daniel recalled that he presented to TEG in November 2015 on what was then called a "Total appraisal" approach[14]. A lot had changed since then, but a lot had not. He drew five conclusions:

- Dynamic clustering is important, but modelling it is also a complex and challenging area.
- Work needs to be guided by the literature, which is vast and evolving.
- There is no "one size fits all" approach. The content is critical and the use of practical tools can be vital.
- Quantification can be challenging, but it is important that it be carried out and done well.
- A great deal more could and should be done in the area.

On the final point, he was very grateful to the NZTA for "setting the challenge" of providing an overview of the subject. He hoped that the study had made a big step, but understanding dynamic clustering was not yet over the final finish line.

Discussion

John Preston noted that the focus of the talk had been dynamic clustering, but was there also an issue of de-clustering? Could the Waterview Tunnel have reduced clustering in the city centre by facilitating inter-suburban travel? **Sandy** confirmed that the tunnel did complete a ring route, and that "de-clustering" would have been termed displacement, which is a negative benefit, and the analytical funnel had been used to consider these effects and to check that the scope of the analysis was correct. **Daniel** agreed that effort had been made to consider this, but noted that clustering in one place means de-clustering elsewhere by definition, and the models should be designed to calculate the net effect. He acknowledged that it was less clear how clustering worked in all cases, citing the TEG meeting itself as a case where the cost of attendance was independent of location on the globe.

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[14] "Total appraisal in practice: the story of the Airports Commission and the Lower Thames Crossing"
https://transecongroup.org/wp-content/uploads/journal/Transport_Economist_42-3.pdf

Adriana Moreno Pelayo noted that there had been papers in the UK on post-COVID model elasticities. Daniel had said that he was a fan of S-CGE rather than LUTI models, but both were hard to understand. **Daniel** said that this was a fair point, and the S-CGE models can be very complex, but then so is the world. Simpler models and sensitivity tests can be used to check the credibility of more complex models.

Tom Worsley congratulated the speakers on a fascinating talk. It was good to see that New Zealand, a relatively small country, was doing all this work. Could the speakers say anything about whether and how the appropriate model parameters and elasticities varied between countries, in the same way that fares elasticities had proven to be broadly similar? Do different "cultures" need different models? **Sandy** thanked Tom for the compliment and said that, while NZTA closely followed work in the UK, it was lucky to have the research programme and to be able to take risks without operational or policy pressure. The applicability of elasticities was a difficult subject. NZTA tends to rely on an Australian database[15] but each elasticity is quite context-specific. NZTA likes to "chip away" at what is important in a particular case or project. It would be a good idea to do a collaborative exercise building on, or analogous to, the Australian example. **Daniel** agreed that elasticities would be quite context-specific, and there would be a need to consider how to make comparisons between countries.

Tali Diamant asked if dynamic clustering, when examined, was the most important effect. **Daniel** said that relocation was useful to understand, but was not necessarily the most important issue: David Metz, for example, might argue that a bigger issue was impacts in land values. **Sandy** added that it seemed methodologically important, but there was a need to think it through: hence the logic maps and methodological funnel.

Joanne Leung asked through the chat what Daniel's thoughts were on agent-based modelling in the future modelling of dynamic aspects of individual and environment (such as land use) changes over time? What was the appropriate balance of effort between different approaches? **Sandy** explained that

[15] https://catalogue.data.infrastructure.gov.au/dataset/transport-elasticities-database

Joanne is at the New Zealand Ministry of Transport which is developing an agent-based modelling tool. **Daniel** said that, in principle, agent-based modelling could be useful, but he had not yet seen good examples of it in use.

David Starkie noted that market failure had been mentioned, but what about the "elephant in the room", at least in the UK, of planning controls? A model might predict a future which was precluded by an overnight change in planning restrictions. **Daniel** agreed and said that it was important to understand not only the existence and impact of these regulations but also the potential impact of changes to them. **Sandy** said he had been involved a 2012 research project[16] featuring anticipatory changes in land use when a transport project was announced and a "planning crayon drew the transport connection". The incoming New Zealand government is interested in the link between how transport influences land use changes and outcomes, so there may be scope to study and clarify it.

Peter Gordon returned to the theme of whether there had been evidence that new assumptions were needed because of COVID. **Sandy** said that he could not say, as he is no longer a modeller, but at least two NZTA projects are considering this. A report due to be published in around two months had found that working from home had reduced commuting, although a bounce back, also seen in Australia, was under way. Other possible COVID-related issues were also being examined.

David Metz said that what was wanted was good predictive power, which means something observable. Property values are observable, but are "agglomeration effects"? **Sandy** said that the original agglomeration elasticities were calculated from micro level business administrative data and could be recalculated from more recent data or from other administrative data sets. This was, however, an issue of evaluation, at which the UK Department for Transport (DfT) had recently become better, at least for major or potentially transformational projects.

Report by Dick Dunmore

[16] https://www.nzta.govt.nz/resources/research/reports/479/

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The Transport Economists' Group, formed in 1973, provides a forum for people involved in transport economics to meet regularly and discuss matters of mutual interest. Membership is open to economists working in transport and others whose work is connected with transport economics.

The aim of the Group is to improve the quality of transport management, planning and decision-making by promoting lectures, discussions and publications related to the economics of transport and of the environment within which the industry functions.

Meetings, online or at Arup's Central London HQ, from September to June (except December), consist of short papers presented by speakers, drawn from both within the Group's membership and elsewhere, followed by discussion.

The Group's Journal, "The Transport Economist", is published three times a year reporting on meetings and other activities of the Group. It reviews recent publications of interest and contains papers or short articles from members. The Editor welcomes contributions for inclusion in the journal, and can be contacted at petersgordon@blueyonder.co.uk.

The current membership of over 150 covers a wide range of transport modes and types of organisation. Members are drawn from transport operators, consultants, universities, local and central government and manufacturing industry. All members are provided with a full membership list, updated annually, which serves as a useful source of contacts within the profession. Applications from people in all sectors are welcome.

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