Department for Transport

LATEST EVIDENCE ON INDUCED TRAVEL DEMAND: AN EVIDENCE REVIEW

An Evidence Review

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EXECUTIVE SUMMARY

WSP and RAND Europe were commissioned by the Department for Transport (DfT) to undertake a literature review on the evidence for induced demand arising from road capacity improvements that will inform the development of the second Roads Investment Strategy 2 (RIS2), covering investment in the English strategic road network between 2020 and 2025.

A major review of the evidence on induced demand was undertaken by the Department for Transport Standing Advisory Committee on Trunk Road Assessment (SACTRA) in 1994. It set out the principal concepts and methods for the treatment of induced traffic, which are also summarised in Mackie (1996). These have since become embodied in the transport appraisal process adopted by the DfT, as described in WebTAG. The current literature review is intended to update the evidence based on induced demand for road travel presented in SACTRA, 1994.

Induced demand for road travel can be broadly defined as **'the increment in new vehicle traffic that would not have occurred without the improvement of the network capacity'.** In cases where network improvements stimulates additional traffic and this additional traffic affects travel conditions, partially recongesting the network, failure to allow for induced traffic may lead to an overestimate of the user benefits of schemes. Therefore unless induced traffic is correctly taken account of, significant errors in benefit estimation can be made. Moreover, in transport appraisal, there is a need to look across all 'travel markets' that are impacted as benefits and/or costs may occur in travel markets from which traffic is displaced. For example, there may be congestion relief on some routes that are not viewed as direct beneficiaries of the project.

The objective of this study was therefore to review the empirical evidence on induced demand, with a view to understanding the size of the effect and where and under what conditions it occurs. In practice, measured induced traffic effects will depend on the time period over which they are measured, the geographical area and whether short-run or long run effects, particularly on land use, are included. While the impact of background growth is not included in this review, empirical studies of induced travel need to control for background traffic growth, as well as traffic changing route (reassigned traffic).

A two stage approach was used to identify a broad range of relevant literature for the evidence review. In the first stage we conducted a systematic search of academic databases for literature published in peer-reviewed journals, conference papers and work undertaken by universities and other institutions, including the DfT. In the second stage, the systematic search was complemented by also contacting key individuals in academia, industry and other stakeholder agencies to identify relevant literature.

In total 25 papers were reviewed, from OECD and European countries.

Evidence was drawn from different methodologies that are not easily comparable.

Much of the evidence reviewed in this report comes from econometric studies, with a smaller body of evidence from case studies and models. Econometric studies report elasticities that represent the percentage change in vehicle kilometres travelled (VKT) relative to a percentage change in road capacity and, in general, consider aggregate changes in capacity rather than specific road schemes.

The evidence from case studies and modelling is reported as percentage changes in traffic relative to the baseline associated with a specific road network improvement. These percentage changes are not related to a corresponding percentage change in capacity and may also be measured in numbers of vehicles rather than vehicle-kilometres travelled. This makes it difficult to compare the case study evidence with the elasticities reported in econometric studies.

Controlling for both background traffic growth and reassignment of road traffic across routes is important for all approaches and can influence the magnitude of the estimates of induced demand.

A wide range of elasticities was reported in the econometric studies reviewed. Case studies also reported a wide range of percentage changes in traffic flows, while those reported by modelling studies were generally smaller.

Induced demand continues to occur and may be significant in some situations.

The evidence reviewed in this study supports the findings of the SACTRA (1994) report that induced traffic does exist, though its size and significance is likely to vary in different circumstances. It was not possible to obtain any qualitative understanding about the composition of induced traffic in terms of new trips, redistributed trips, transfers between modes and trips associated with new developments. There remain wide variations in the quantitative evidence that make it difficult to draw conclusions about the magnitude of the impact of induced demand from road capacity improvements on the Strategic Road Network. However, we draw some tentative conclusions:

- Findings for state level road networks in the US and the national Dutch network indicate an elasticity of around 0.2 across the whole road network, i.e. a 10% increase in road capacity could lead to 2% induced demand on the network.
- It is not possible to reconcile the case study evidence and the econometric results because the two types of evidence are presented differently.
- Induced demand is likely to be higher for capacity improvements in urban areas or on highly congested routes. There is little evidence that extreme levels of induced demand would occur on the Strategic Road Network although on highly congested parts of the network there may be a clear localised response.
- The evidence on the existence of induced demand means that it needs to be properly accounted for in the appraisal of capacity improvements to the Strategic Road Network.[1] The demand impacts on other travel markets need to be quantified as part of this appraisal but there is a lack of evidence on the source and size of these impacts.

There are a number of areas that would benefit from further work:

- Case study evidence is limited. Although there are major difficulties in designing a study to collect robust data (Rohr et al, 2012), it would be useful to be able to generalise more from specific case study examples to different types of road improvements. These could be categorised by scheme type but also by area type and geographical scale. More data related to the scale of the improvement relative to the network of interest would also be required.
- The evidence base on induced travel is mainly from outside the UK. Some econometric evidence, in particular, mainly relates to increases in road capacity in large metropolitan areas, which may not be directly relevant to road building in the UK. Appropriate econometric analysis based on UK data would provide a useful addition to the evidence base.

There is very little evidence on the composition of induced traffic in the short or long run. This is an important issue for transport appraisal, where induced road traffic may come from other modes or result from economic growth due to land-use development associated with the transport investment. There may also be additional traffic resulting from changes in land use such that residences or business locations have transferred from other areas. Determining how best to measure this effect is itself an area for research. The geographical scale for measurement and appraisal becomes important in determining whether these are included as induced traffic.

[1] Modelling of Variable Demand responses is out of the scope of this evidence review and the relevant DfT guidance is found in TAG Unit M2: https://www.gov.uk/government/publications/webtag-tag-unit-m2-variable-demand-modelling-march-2017.

1 INTRODUCTION

1.1 BACKGROUND

1.1.1. WSP and RAND Europe were commissioned by the Department for Transport (DfT) to undertake a literature review of the evidence on two key analytical questions that will inform the development of the second Road Investment Strategy 2 (RIS2)[2] covering investment in the English strategic road network between 2020 and 2025.

1. What does the evidence say on traffic growth trends?
2. What does the evidence say on induced demand?

1.1.2. In order to meet the DfT's objectives, it was essential that each review:

- Discuss and summarise what recent literature says on these issues for the Strategic Road Network (SRN), specifically with regard to demand for investment in new roads.
- Quantify how robust the evidence is in each area, including the data used, assumptions made, analysis methods and relevance of the evidence.
- Identify gaps in the evidence base, including whether further work, and what work, is required to be able to robustly address the key research questions.

1.1.3. It was emphasised that the aim of this study is to review 'new' research/evidence and not to make recommendations about changes to modelling/appraisal methods. Further, the literature review should identify high quality literature and cover European and wider international evidence.

1.1.4. The evidence from the literature review on induced demand is presented in this report. The implications of the evidence for economic appraisal of transport projects are also discussed. Evidence on traffic growth trends is presented in a separate report.

1.1.5. This report is organised as follows. In Chapter 2, we introduce the concept of induced demand and provide definitions and notation. The link between induced demand and transport appraisal is also described. In Chapter 3, we describe the literature review methodology. In Chapter 4, we summarise the evidence on induced demand. This chapter also covers the robustness of the evidence and identifies factors that influence the evidence on induced traffic. Chapter 5 discusses the overall findings from the different evidence sources and their relevance for the SRN. It concludes with some recommendations for steps that can be taken to address the evidence gaps. The implications for transport appraisal are addressed in more detail in an Appendix A.

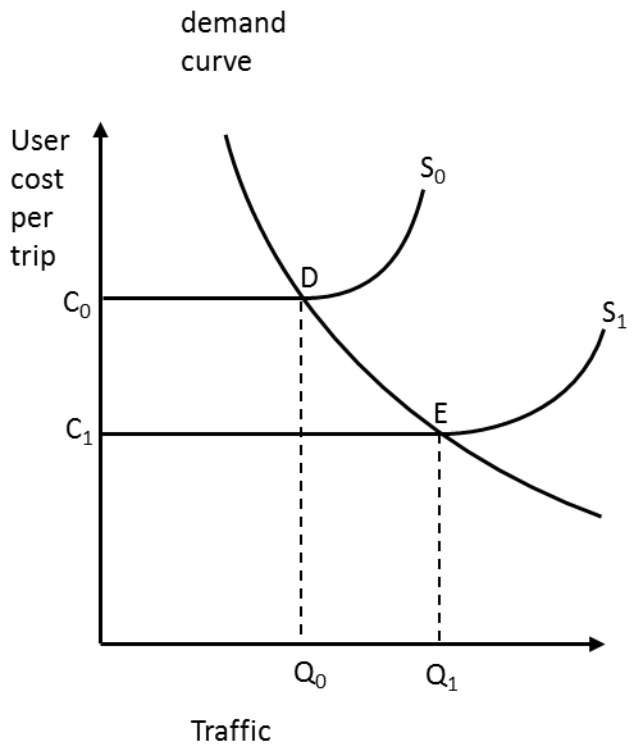
[2] The first Road Investment Strategy (RIS1) covered investment in England's motorways and major roads (the 'strategic road network') during the 2015 to 2020 period. This was the initial step in a long-term programme to improve England's motorways and major roads. This process is repeatable and work is now underway to develop the second RIS, known as RIS2, covering the second road period post 2020.

2 INDUCED DEMAND AND ECONOMIC APPRAISAL

2.1 WHAT IS INDUCED DEMAND?

2.1.1. Economic theory tells us that generally if there is a reduction in the price of a good or service, demand for it will increase. This principle also applies to the demand for transport.[3] In this case, however, the price of transport reflects all costs associated with travelling, such as the time taken, in addition to out-of-pocket costs. This is referred to as the 'generalised cost' of travel. If there is a change in this generalised cost of travel[4] [5] then there should be a change in demand for travel. This applies to any mode of transport. However for this study we are focussed on road travel in particular.

Figure 2.1 - Demand and supply curves for road travel



2.1.2. Figure 2.1 shows that a shift in the supply curve (from S0 to S1) would decrease the equilibrium generalised cost of road travel (described as the user cost per trip) from C_0 to C_1. Such a shift could be caused by a variety of measures, from policies aimed at reducing congestion to the provision of new infrastructure. [6] For the purposes of this study, we are interested in the demand response to increased physical road infrastructure capacity, i.e. new road building and road widening, and, more specifically, from improvements to England's motorways and major roads which is the focus of RIS2. These improvements in the main are likely to add additional capacity and may reduce the cost of travel by improving travel times, often by reducing congestion or by increasing the accessibility of locations. A capacity improvement that reduces the cost of travel will also

[3] Transport is a derived demand in that consumers use transport to access activities.

[4] Generalised cost of travel refers to both the monetary (out-of-pocket costs) and non-monetary costs of travel (for example, travel time).

[5] The degree of responsiveness is measured by the elasticity of demand - the percentage change in demand in response to a percentage change in the generalised cost of travel. An elasticity of -0.5 would mean that a 10% decrease in cost would result in a 5% increase in demand. Perfectly elastic and perfectly inelastic demand represent the extremes where either all traffic chooses to use the route at the given cost or any change in cost would not result in a change in demand, respectively.

[6] A change in generalised cost can also result from changes in direct out of pocket costs, such as fuel costs. A decrease in fuel costs per kilometre can also occur through improvements in fuel efficiency; this is known as the rebound effect.

lead to an increase in the demand for travel[7] so that, in equilibrium, the demand shifts from Q_0 at cost C_0 (D) to Q_1 at cost C_1 (E), as shown in Figure 2.1. The additional demand is essentially induced.

2.1.3. For transport appraisal purposes it is important to understand what elements of measured traffic are included in induced demand. This is considered further below.

2.1.4. A major review of the evidence on induced demand was undertaken by the Department for Transport Standing Advisory Committee on Trunk Road Assessment (SACTRA) in 1994. As noted in the SACTRA report, travel is rarely an end in itself and provides the means to undertake activities (e.g. work or business related activities, leisure and shopping). Changes in individual travel behaviour in response to new road capacity may occur for a number of reasons. Individuals may change the volume of activities they undertake, the location and timing of these activities, how the activities are co-ordinated and the mode of transport and route used to access the activity. However, not all of these responses result in induced travel.

2.1.5. A widely used definition for induced demand for road travel can be summarised as **'*the increment in new vehicle traffic that would not have occurred without the improvement of the network capacity*'**, where traffic is usually measured in vehicle-kilometres travelled (VKT).[8] SACTRA (1994) also defines induced travel in terms of VKT. This measure of induced travel means that there can be induced travel when the number of trips undertaken is fixed, for example if people travel longer distances. It is noteworthy, however, that this definition does not specify the period of measurement – in terms of time of day or whether short-run or long-run effects are included – the area over which the traffic volume is measured or the types or roads to be included.

2.1.6. There are a number of terms that are commonly used in transport modelling and appraisal that it is useful to define in the context of induced traffic. The SACTRA report was careful to distinguish induced traffic from traffic generation, a term often used by transport modellers that defines the number of trips made by a specific population over a given time period and specific geographical area. Of course the introduction of new infrastructure could give rise to induced travel through increases in trip rates if people make new trips that they weren't previously making. For consistency and clarity, we too use the term induced travel in this report. Further, in transport modelling a change in route for a trip between a fixed origin and destination is known as re-assignment. Redistribution occurs when either the origin or destination also changes. Re-assignment and redistribution contribute to induced traffic when there is an associated change in trip length.[9]

2.1.7. Based on these definitions, induced traffic can then be considered to consist of the change in traffic VKT on a network that results from a change in:

- Mode of travel, e.g. switching from public transport to driving;
- Frequency of travel, specifically in terms of making additional trips that were not made previously;
- The distance travelled by changing route to the same destination or to a new destination;
- The distance travelled by changing destination (change location of activities); and
- In the longer term, the distance travelled due to changes in residential or employment location or as a result of changes in land-use.

2.1.8. A change in trip timing is also not usually considered an induced demand effect if the trip is still made within the measurement period of interest.

2.1.9. While changes in mode, frequency and distance of travel and even changes in location of activities may be considered short-run effects, the time period over which these effects may occur is not clear cut. The decision to change mode may involve the purchase of a car, for example. This is also true for long run effects which depend on decisions to move house or change job location; decisions that also depend on other, non-transport related factors.

[7] Assuming demand is not perfectly inelastic.

[8] We return to a discussion of the definitions used in the papers reviewed in this report in Section 4.3,

[9] Some may argue that trip reassignment should not be included in induced travel. We choose to include all possible responses that lead to changes in vehicle-kms in our definition and this includes the additional (reduced) vehicle-km associated with a re-assigned trip. Further, we emphasise that definitional differences do not influence our work in terms of summarising the evidence on induced travel effects. Although they will influence the size of such effects and where the evidence permits we will identify what responses are considered in the published values. We further note that reassigned and redistributed traffic depend on the specification of geographical area and time period.

2.1.10. The effect of road capacity improvements on land-use patterns through developments is an important consideration for induced traffic. In many circumstances, particular developments may be linked to the road capacity improvement. Additional vehicle km arising from land-use development that can be attributed to a road-network capacity improvement would be considered induced traffic. These may occur in the shorter or longer term. For example, as a result of new road infrastructure, a developer may build a new retail park. New trips made to this facility would result in induced traffic. However depending on the area of interest, some of these could be redistributed trips. The situation becomes less clear for changes in residential location and employment locations in the longer term. These may be in response to the changes in the road network but are difficult to define.

2.1.11. The induced travel effects listed above need not all result in an increase in road traffic. For example, changing routes or destinations could lead to shorter distances being travelled; Alleviating a congestion bottleneck on a more direct route by increasing capacity means that drivers can now take the direct route and no longer need to take a longer, more indirect route to their destination to avoid the bottleneck. Moreover, it is important not to focus on a single market where a capacity expansion may induce demand as significant benefits may occur in other 'travel markets' from which traffic is displaced.

2.1.12. In practice, measured induced traffic effects will depend on the time period over which they are measured (e.g. peak hour or daily averages) the geographical area and whether short-run or long-run effects, particularly on land use, are included, although these factors are not generally clearly specified in the definition of induced demand. This may be due to the availability of data, the appraisal framework or the focus of the study. Another issue of measurement will be increases in background traffic growth as a result of changes in exogenous factors such as GDP. While, the impact of background growth is not included in this review, empirical studies of induced travel need to control for background traffic growth, as well as re-assigned traffic and this is not always straightforward. We return to these issues in Chapter 4.

2.1.13. Finally we emphasise that induced travel is not necessarily a bad thing: new infrastructure may encourage drivers from local roads to the strategic road network – reducing local congestion, provide people with increased accessibility to activities or encourage new businesses to locate to areas with new infrastructure, which may be positive for society, even if travel is increased. The overall impact of induced travel arising from a road infrastructure improvement is quantified by calculating the benefits across all relevant markets. This is discussed in the next section.

2.2 INDUCED DEMAND AND USER BENEFITS

2.2.1. In this section we provide a brief discussion of the relationship between induced demand and economic appraisal. A detailed exposition of the relationship is set out in Appendix A. The principal concepts and methods for the treatment of induced traffic are set out by SACTRA (1994) and also summarised in Mackie (1996). These have since become embodied in the transport appraisal process adopted by the DfT, as described in WebTAG.[10] [11]

2.2.2. One aspect of an appraisal is the measurement of changes in consumer surplus – the change in the net benefits obtained by transport users from making a trip. For a given volume of traffic, consumer surplus is measured as the area beneath the demand curve and above the generalised cost paid by users. The demand curve represents marginal willingness to pay for each trip. When the area between the demand curve and the prevailing cost of travel is summed over the volume the result is total consumer surplus in the transport market. The supply curve represents the marginal private cost of travel. When summed over volumes of trips at the prevailing cost of travel, the result is the total consumer surplus.

2.2.3. Road investments will tend to reduce the level of generalised cost for each level of demand, shifting the supply curve downwards. This will lead to increases in the volume of trips – known as induced demand. For a specific road intervention the change in consumer surplus (termed user benefits in transport analysis) is measured by the area C_0DEC_1. This represents an increase in transportation consumer surplus. Consequently whilst road investments generally lead to greater volumes of trips, those extra trips go hand in hand with increased consumer surplus (user benefits).

[10] WebTAG is Transport Analysis Guidance provided by DfT on transport modelling and appraisal.

[11] Having said that, the treatment of land use change induced by a transport investment remains problematic in appraisal and remains one of the topics where further research is needed.

2.2.4. Consumer surplus incorporating induced traffic (Area C_0DEC_1 in Figure 2.1) can be measured using the Rule of Half (RoH). The RoH uses a linear approximation to the demand curve, but is adequate in most circumstances. The user benefit comprises of the benefit to the existing traffic (Q_0) and the induced traffic (Q_1-Q_0).

2.2.5. Appraisals always need to be holistic, and with induced traffic that point is never more pertinent. There is a need to look across all 'travel markets' that are impacted. This is because benefits and/or costs may occur in travel markets from which traffic is displaced. For example, there may be congestion relief on some routes or between some origin-destination pairs that are not viewed as direct beneficiaries of the project. Furthermore, induced road traffic also has implications for government revenues (through changes in indirect taxation), and can also impact on public transport operators fare revenues and costs. Induced traffic will also create changes in safety and environmental costs.

2.2.6. Suppressed demand is argued to occur if background traffic growth increases congestion levels and therefore crowds out some trips from the network. Suppressed traffic is really just the opposite effect of induced traffic. That is induced traffic occurs when the generalised cost of travel decreases. If the generalised cost of travel increases (e.g. through background traffic growth increasing congestion) then we see suppressed travel, which will become induced travel if a transport project decreases generalised cost. The RoH accommodates both suppressed and induced traffic.

2.2.7. Induced traffic adds to the economic value of a scheme. This added value can be seen in Figure 2.1 as the area under the demand curve, between traffic volumes Q_0 and Q_1 and above generalised cost C_1. In uncongested conditions it does so without imposing congestion costs on the base traffic (Q_0). However, in congested conditions the induced traffic imposes a congestion cost on the base traffic. This cost can be highly significant. Therefore unless induced traffic is correctly taken into account in appraisal, significant errors in benefit estimation can be made. This is a key point from SACTRA 1994 and summarised in Mackie 1996 and Coombes 1995.

2.2.8. In the extreme scenario that a new road fills up, or nearly fills up, with induced traffic, benefits will still be derived from parts of the network relieved of traffic. Benefits will also occur for those who change behaviour as a consequence of the project (switching time periods, destinations, origins, etc.). The conditions for no benefits to occur are quite stringent and unlikely to be applicable on the UK's Strategic Road Network.

2.2.9. Where induced traffic is due to land use and/or economic growth stimulated by the transport project, these land use change benefits and/or costs need to be captured. The changes in land use only have additionality to the user benefits if a market failure exists. This is a key element of the DfT's wider economic impacts guidance. This remains an ongoing area of methodological development and remains on the knowledge frontier.

2.2.10. If generalised cost changes are large, the linear approximation in the demand curve of RoH is not viewed as sufficiently accurate. DfT guidance recommends the use of numerical integration if cost changes are greater than 30%, but alternatives to this method also exist (e.g. a direct integration of the demand curve[12]).

2.2.11. The rest of this report is concerned with the empirical evidence on induced traffic. From an appraisal perspective we are particularly interested in:

- Whether there is strong evidence for induced demand on the Strategic Road Network, as this would imply that appraisal methods (and demand forecasting in particular) need to be cognisant of induced traffic.[13]
- The scale of the response. Is there evidence that new roads 'fill up'?
- Evidence on land use change as a response to transport investment, as this pushes the boundaries of current appraisal methods, if we wish to capture all costs/benefits.

[12] For example, the logsum gives the consumer surplus from the direct integration of the demand curve, when that curve has a logit formulation.

[13] Modelling of VDM is out of scope of this review and the relevant DfT guidance is TAG Unit M2: https://www.gov.uk/government/publications/webtag-tag-unit-m2-variable-demand-modelling-march-2017.

3 LITERATURE REVIEW METHODOLOGY

This chapter sets out the literature review methodology used to gather evidence on the scale of induced travel as a result of road infrastructure changes.

3.1 SEARCH METHODOLOGY

3.1.1. A two stage approach was used to identify a broad range of relevant literature for the evidence review. First we conducted a systematic search of academic databases for literature published in peer-reviewed journals, conference papers and work undertaken by universities and other institutions, including the DfT. While this search methodology also picked up grey literature (broadly defined as unpublished or non-peer-reviewed studies), particularly reports published by large agencies, it does depend on the search strategies employed. The systematic search was complemented by also contacting key individuals in academia, industry and other stakeholder agencies to identify relevant literature. This served both to identify additional relevant evidence from studies in which induced demand or synonymous terms do not appear in the title, abstract or keywords or grey literature not picked up in the systematic search, as well as to identify a set of papers that could be used to pilot the systematic search strategies (specifically to test whether the systematic search strategy picked up key publications).

SYSTEMATIC LITERATURE SEARCH

3.1.2. A rapid evidence assessment (REA) was used for the literature search. This type of review aims to be a comprehensive, systematic and critical assessment of the scope and quality of available published evidence. REAs follow a similar structure to systematic literature reviews, as outlined in the Government Social Research Network Guidance, in that they aim to be replicable and transparent, yet they have the advantage of being less resource intensive. This is achieved by formally constraining the types of research to be reviewed, for example, by location, language and publication date. In the context of this study an REA was appropriate as it allowed the literature search to focus on evidence published in the UK, while capturing the most relevant data from other developed countries; a restriction on publication date also helps strike a balance between the need for evidence on trends and avoiding duplication of previous work.

3.1.3. A search protocol was developed to capture relevant evidence on induced demand as specified in the research question (see Appendix B for the detailed search protocol). The search protocol consists of search strategies and inclusion criteria. A number of separate, but not mutually exclusive, search strategies were implemented to cover as much relevant literature as possible without generating an unmanageable number of results. The search terms were piloted on papers already known to the review team and provided by key contacts to test their efficacy and the final set of search terms was able to identify these papers. The final search terms were in fact very broad to avoid omitting any relevant literature. The main inclusion criteria were:

- Studies providing evidence on induced demand as a result of an increase in road capacity. Evidence on the relationship between road capacity increases and travel time and between travel time and induced demand were considered to be out of scope.
- English language studies from OECD/EU countries to minimise issues of transferability.
- Studies published in or after 2007, which was judged reasonable to return enough of the most recent evidence. Earlier papers known to the study team or provided by key contacts were included if relevant.
- Quantitative, empirical studies based on observed data. Modelling studies that explicitly covered induced demand.
- Studies covering induced traffic from road passenger transport and road freight transport.

3.1.4. The searches were conducted in three literature databases to ensure broad coverage of the literature: the Transport Research International Documentation (TRID) database, Econlit and Web of Science.[14]

[14] The TRID database integrates the content of two major databases, the Organisation for Economic Co-operation and Development's (OECD's) Joint Transport Research Centre's International Transport Research Documentation (ITRD) Database and the US Transportation Research Board's (TRB's) Transportation Research Information Services (TRIS) Database. Econlit is the American Economic Association's database on worldwide economic literature, including peer-reviewed journal articles, working papers from leading universities, PhD dissertations, books and conference proceedings. Web of Science is a citation index, with 5294 publications in 55 disciplines as well as 160 000 conference proceedings.

KEY CONTACTS

3.1.5. In parallel, we contacted 33 researchers and practitioners by email, known by the study team to have expertise relevant to induced traffic[15], to identify additional resources and grey literature. We had a very positive response, with nearly three-quarters of the experts responding providing a substantial number of additional publications and grey literature. While there was some duplication of the academic literature, this approach was designed to capture recent developments in the literature that may not yet have followed the peer review process and high quality industry reports.

ASSEMBLING THE LITERATURE

3.1.6. The database searches were first screened using titles and abstracts of studies identified from the literature search ('first-pass'). The first screening phase was conducted within Endnote – specialist reference management software – and was based on the inclusion criteria from the search protocol outlined in 3.1.3 above. A similar approach was used to screen literature obtained from contacts. The resulting longlist was then screened a second time, in conjunction with senior project team members and the DfT to determine the list of final papers to be included in the review.

The final short-list of papers to be reviewed consisted of 24 papers. These papers were selected as far as possible to cover a range of interventions and provide evidence relevant to the UK. One additional paper was reviewed during the course of the study.[16] The full list of papers reviewed can be found in Table 4-2 (Chapter 4 and in the references. In total, 25 papers were reviewed.

3.2 REVIEW OF THE LITERATURE AND DATA EXTRACTION

3.2.1. A data extraction template was set up in Excel to collate the data collected from each study. The information recorded from each study reviewed, where available, consisted of:

- Study identification information – number, authors, publication date
- Publication type (journal, report, conference proceedings,…)
- Study location/country
- Definition of induced demand used in study
- Evidence type (econometric, case study, model,..)
- Details of methodological approach (variables included, regression type,…)
- Sample size, time period of data collection
- Intervention (new road, road improvement)
- Geography/scale (urban/interurban, project level, county/state, national)
- Timescale (short run/long run)
- Evidence on induced demand.

3.2.2. Categorising the evidence on induced traffic according to the above criteria allows studies to be reviewed in a consistent way. For comparison, it is particularly important that any differences in the definition of induced demand are made clear, as well as the type of road capacity increase studied and the scale at which the induced demand effect is determined. Some of the above criteria relate to the potential transferability of the evidence on induced traffic from other locations to the UK, and particularly to the SRN.

3.2.3. An assessment of quality was made based mainly on methodological criteria and data quality considerations, although publication type was also taken into account. The data extraction criteria are used to provide a framework for assessing the evidence in Chapter 4.

[15] Individuals were approached for information on both road traffic growth and induced road traffic in a single email.

[16] This was a relevant European PhD thesis (Pasidis, 2017), that was provided by an expert contact after the initial selection was made.

4 EVIDENCE ON INDUCED TRAVEL

In this chapter we present the evidence on induced demand and discuss the main factors that influence the reported values. Section 4.1 provides an overview of the main characteristics of the papers selected for review. Grouping studies according to methodology, the evidence on induced demand reported in the reviewed papers is then summarised in Section 4.2. Section 4.3 concludes with a discussion of the main factors that need to be considered in the interpretation of the evidence. A synthesis of the evidence, taking into account the key issues that were identified in Section 4.3, is provided in Chapter 5, together with the implications for transport appraisal.

4.1 OVERVIEW OF PAPERS SELECTED FOR REVIEW

4.1.1. As described in Chapter 3, 25 papers were reviewed. The main characteristics of these studies are summarised in Table 4-1.

Table 4-1 Summary of main characteristics of the reviewed papers

Publication date	2001-2017
Methodology used	case study (4), econometric (12), model (4), review (5)
Geographical coverage	UK (3), Europe (7), USA (8), other (3), international (5)
Paper type	journal (15), conference (4), report (3), book chapter (1), PhD thesis (1), Working Paper (1)
Road investment	non-specific investments (13), projects (7)
Measure of induced traffic	elasticity (16) , other (7), not relevant (2)

Note: The geographical coverage of review studies is denoted as international. Some studies cover more than one geographical location. The investment types of papers from review studies are not included in the table.

4.1.2. Non-specific investments encompass increases in road capacity, usually measured as aggregate increases in lane-kilometres that are not linked to a particular project.

4.1.3. The studies included in the review have been categorised as case studies, econometric studies, models or reviews. These are defined as follows:

- Case studies: Studies of a particular project and location, generally using a before/after approach.
- Econometric: Using statistical methods to empirically test an economic hypothesis, generally using data over a period of time and from a number of locations.
- Model: Development of a model to describe land-use and/or travel demand behaviour that is then used to quantify induced travel.
- Review: Literature review/other compilation of evidence on induced travel.

4.1.4. The papers that have been reviewed provide a reasonable geographic coverage. The five review papers provide summary data on induced demand from international studies. However, these mainly reported on econometric studies, predominantly using data from the USA.

4.1.5. The different types of papers also differ in the type of road investments covered and measure of induced traffic. In the econometric papers, additional road capacity is measured in terms of lane-km and the induced traffic effect as an elasticity of vehicle-kilometres travelled (VKT) with respect to lane-kilometres. For case studies and models, the induced traffic effects are mainly presented as percentage increases in trips or annual average daily traffic flows (AADT) in response to a specific transport infrastructure investment. A variety of infrastructure investments were covered including road widening, new trunk roads and bypasses.

4.1.6. We report the evidence on induced travel from these different sources in the following section and discuss the impact of study methodology, measures of road investment and induced travel, location and geographical scale. We also discuss the quality of the available evidence. It is emphasised that it was not within the scope of the study to undertake a quantitative meta-analysis of the outcome data. This is something that is discussed further in evidence gaps in Chapter 4.

4.2 FINDINGS ON INDUCED TRAVEL

4.2.1. Below we summarise key findings on induced travel from case study, econometric and model evidence.[17]

CASE STUDIES

4.2.2. Four papers reporting case study evidence were reviewed. Three of the case studies use observed data measured before and after the implementation of road schemes but require additional analysis to determine the induced demand effect.

4.2.3. Davies (2015) compares growth in traffic volumes (VKT) for seven schemes in Queensland, Australia, measured relative to the projected baseline without the scheme in place, so that background traffic growth is accounted for.[18] It is not clear however, if re-assignment of traffic from other routes is included or excluded from the induced travel estimates. The schemes included motorway upgrades, new alternative routes, additional lanes and bypasses. Relative to the baseline, traffic flows were found to increase by between 17 and 38 per cent within two years of construction. Interestingly, this study calculated volume to capacity ratios for the schemes and baseline flows. The highest increases in traffic volumes were found to occur for schemes where the baseline traffic volume was high or the route was close to capacity. Assuming that the percentage change in volume relative to the percentage change in capacity provides a rough elasticity estimate, the data from this study indicates elasticities of 0.5 to 1 for the congested and high volume routes but much smaller elasticities for other schemes.

4.2.4. Case study evidence for the UK comes from Sloman et al. (2017) - who looked at a range of road improvements - and Rohr et al. (2012) who calculated induced traffic for the Manchester Motorway Box[19]. Sloman et al. (2017) use a screenline approach to control for re-assignment and also report that they control for background growth.[20] They calculate induced traffic as the percentage change in traffic flows, where traffic flows are based on trips (AADT or equivalent) and not distance travelled. As noted earlier, these measures are reported to be in excess of background traffic growth, which has been based on the average regional and county comparators over the same period.[21] They found induced traffic for eight out of nine schemes[22] in the range 5 to 10 per cent but 20 per cent for the M25. They report a short-run average increase of 7 per cent for seven schemes and a long run average of 47 per cent based on six schemes for which data were available 8 to 20 years after implementation.[23] The study covers a range of improvement types and sizes (length, number

[17] Throughout we use metric measures (e.g. VKT and lane-km) for consistency although this notation may differ from that actually used in the papers reviewed.

[18] The authors compared average data for years prior to construction with the BITRE aggregate forecast for Queensland and identified a linear growth trend that was applied as the baseline.

[19] We have categorised the Manchester Motorway Box study as a case study – on the basis that the study was focussed on the impacts of a specific investment and used before and after data. However, in order to assess the impacts of the infrastructure a model was developed. Thus it could also be categorised as a modelling study.

[20] A screenline is an imaginary line that splits a study area into a number of parts, usually along physical barriers such as rivers, railway lines or roads. The screenline is a control line that is used for measuring and comparing traffic count data. Ideally screenlines will measure traffic by all modes that cross it, thus allowing estimates of increases in traffic and mode switching.

[21] If road investments tend to be made in areas with increased growth, using a regional average may underestimate growth effects and therefore overestimate induced traffic effects.

[22] These were the A500, A66, A1, A1(M), A5, M1, A10, A30 and M25. Four case studies were additionally undertaken on the A34 Newbury Bypass, M65 Blackburn Southern Bypass, A46 Newark – Lincoln and A120 Stansted to Braintree schemes.

[23] The overall averages presented include studies for which screenline data were not available. These were the M25, A1(M) and M65. The SR average includes all studies with data from 3-7 years after opening. For the LR calculations, data for the four case study schemes for which screenline data are available are presented in the report (Table 11.1). These give a simple average of 38%.

of lanes), although it is not possible to determine the capacity increase that these scheme improvements represent.

4.2.5. The opening of the Manchester Motorway Box completed one of the last major links in the UK motorway network and the scale of the new road infrastructure investment meant that its completion in October 2000 provided an opportunity to collect data to attempt to measure the extent of induced traffic effects. Travel survey data were carefully collected for car and public transport users across key screenlines before and after the opening of the Manchester Motorway Box. In order to quantify the impact of different travel behaviour responses a travel demand model was developed using the disaggregate data, plus household survey data collected between the before and after periods (Rohr et al. 2012). The model reflected trip frequency (generation), mode, destination and time-of-day choice decisions. The model was then used to quantify the impact of the infrastructure investment. Using this approach, the authors found a 15 to 17 per cent increase in car trips across the relevant screenline, of which the majority were attributed to changes in destination (9 per cent) and less to mode shift (4 per cent). Demographic and employment effects were explicitly accounted for using detailed land use data for the area and accounted for between 2.5 to 3 per cent of the changes.

4.2.6. The fourth case study (Nicolaisen & Naess, 2015) primarily focused on the inaccuracy of do-nothing forecasts for transport appraisal. Using statistical analysis of 20 road projects in the UK and 15 in Denmark, for which the do-nothing case could be empirically established[24], the authors found a systematic bias towards overstating the forecast of do-nothing demand. This is an important issue as induced demand is determined in appraisal by comparison of do-something and do-nothing scenarios. It is also relevant for the case study evidence that relies on establishing a counterfactual in order to determine induced traffic. However, this study does not provide empirical evidence on induced demand from the implementation of road projects.

ECONOMETRIC STUDIES

4.2.7. Twelve econometric studies published after 2006 have been reviewed. These studies aim to analyse the relationship between induced travel (measured by VKT) and road capacity (generally measured by an increase in lane-km) using empirical data. To do this most studies employ a regression approach, typically of the form:

$$Log(VKT_{it}) = \alpha_i + \beta_t + \gamma Log(lane-km_{it}) + \sum_k \delta_k X_{kit} + \varepsilon_{it} \qquad (1)$$

4.2.8. Where subscripts i and *t* refer to area and time period and X represents a set of *k* control variables. Using logarithmic forms of the dependent VKT and lane-km variables means that the coefficient γ can be interpreted as the elasticity of VKT with respect to lane-km; the proportionate response in demand to an increase in road capacity.[25] In some formulations, lagged VKT terms are included as explanatory variables[26], allowing a long-run elasticity to be inferred as well as other lagged variables to account for delayed behavioural responses.

4.2.9. The elasticity represents the proportion of new capacity that is taken up by demand. Hence, if the elasticity is 0.5, a 10% increase in network capacity would result in 5% more traffic on the road network. Short run elasticities are expected to reflect the demand response arising from changes in mode, frequency of travel and destination as a result of new capacity. Long run elasticities are additionally expected to reflect demand responses as a result of changes in residential and employment location or land use and are therefore likely to be higher. In both cases the sources of induced demand are not often disaggregated. If road capacity is a proxy for generalised cost, then a higher elasticity is indicative of a flatter demand curve. This could be the result of highly congested conditions with suppressed demand, so a small decrease in the cost of travel results in a large increase in demand. In the long run the higher response can be thought of as a shifting (rotation) outward of the demand curve as there is more demand over time from users who have relocated or to new trip patterns due to land developments.

[24] For example, projects, for which do-nothing forecast were made, were then cancelled, so that do-nothing could be observed.

[25] Differentiating (1), one obtains $\frac{lane-km}{VKT}\frac{\partial VKT}{\partial lane-km} = \gamma$

[26] i.e. VKT from period t-1, t-2 etc. would appear on the right hand side of equation 1 to explain VKT in period t.

4.2.10. It is important to note that the elasticities are calculated from aggregate data. The measured VKT includes background traffic and re-assigned traffic as well as induced traffic, as defined in this study (i.e. induced demand comprises changes in VKT from changes in mode, destination, distance travelled. frequency and land-use effects; reassigned traffic comprises VKT from changes in route or destination that do not add additional VKT). Hence the extent to which the elasticity represents induced demand depends on how the study controls for background traffic growth and re-assignment of traffic from other road types, etc. Within the estimation framework presented in equation(1), different approaches and datasets are used. These are discussed in the context of each study and we return to their implications for the reported elasticities in Section 4.3.

4.2.11. There are two main groups of econometric studies that differ in terms of geographical coverage and methodological approach.[27] These are discussed separately next. The section concludes with the evidence from two further papers.

Evidence from the state or regional level

4.2.12. There are five studies that examine the relationship between VKT and road capacity at the US state level. Hymel et al. (2010) use a simultaneous equations model for VKT on all road types.[28] This approach should mean that re-assignment is controlled for as a route change will not have an impact on total VKT unless the journey length also changes and this latter effect is considered part of induced demand. They control for vehicle stock, income, fuel price and population, as the main determinants of background growth[29] and find short-run (SR) and long-run (LR) elasticities of 0.032 and 0.16 respectively. Using urban lane miles and road length per square mile as capacity measures, 40 per cent of the elasticity is attributed to urban road expansion. Su (2013) uses a similar approach on a slightly more recent dataset and obtains larger elasticity values, although they are a similar order of magnitude (0.066 (SR), 0.26 (LR)). Noland (2001) calculated short-run and long run elasticities of 0.119 and 0.36, using a distributed lag model, including the same controls as Hymel et al. (2010) apart from vehicle stock. Using a proxy measure of road capacity expansion (productive capital expenditure) and controlling for population, income and fuel price, Concas (2013) estimates similar values (0.041 (SR), 0.237 (LR)). In contrast to Hymel et al. (2010), Rentziou et al. (2012) find a larger effect on VMT of urban road capacity (0.267) than rural road capacity (0.086) using lane-miles for both.

4.2.13. Gonzales and Marrero (2012) estimate elasticities for Spanish regions. Again, using a similar set of variables these authors found short run and long-run elasticities of a similar order of magnitude to the US studies.

4.2.14. Noland (2001) and Rentziou et al. (2012) both use the same approach[30] to quantify the elasticity of VKT with respect to increases in lane-km for different road types, specifically Interstate Highways, arterial and collector roads. The elasticities by road type are somewhat higher than the general values (Noland: 0.3-0.6 (SR), 0.7-1.0 (LR), Rentziou et al. 0.272 to 0.531 for urban roads). Only Rentziou et al. (2012) accounts for cross effects of capacity increases on one road type on VKT on another (e.g. the impact of Interstate Highway (IH) capacity on arterial VKT). However, they do not appear to find any re-assignment (negative cross effects).

4.2.15. These studies estimate relatively low elasticities for VKT on all roads. Higher values are estimated when different road types are considered separately.

Evidence from large urbanised areas

4.2.16. Another group of studies consider changes in demand at the metropolitan area level. These areas are not restricted to purely urban settings but vary quite widely in geographical size and population density.[31] Three of the studies apply a similar approach but use data from different countries. In particular they use data from planned road and rail networks as instrumental variables (IV) to represent the effect of increases in road

[27] The studies use different estimators and different forms of instrumental variables (IV) to control for effects such as endogeneity and omitted variable bias. We briefly discuss some methodological implications but a detailed analysis of the effect of the different estimation methods is beyond the scope of this study.

[28] Four simultaneous equations in VKT, vehicle stock, fuel efficiency and congestion are estimated.

[29] This accords with our findings in Rohr et al. (forthcoming).

[30] Seemingly Unrelated Regression Equations (SURE)

[31] This is discussed in Section 4.3.

capacity that influence VKT alone.[32] These studies estimate a long run elasticity of demand with respect to road capacity to analyse the impact of increases in road capacity on congested networks.

4.2.17. The first of these, Duranton & Turner (2011), use data from 228 Metropolitan Statistical Areas (MSAs) in the US and find large elasticities for IH demand with respect to IH capacity in the range 0.82 to 1.39, with the authors preferred value, 1.03, across all estimation methods used. Comparing the IV results with other estimation methods, the IV elasticities are generally 0.1 to 0.2 higher. MSAs are not purely urbanised and the analysis shows slightly lower elasticities of around 0.8 for non-urban IHs and major urban roads.

4.2.18. An elasticity of one would mean that every additional lane-km added to the network is completely absorbed by a corresponding increase in VKT and there would be no reduction in overall travel times.[33] This is essentially the 'fundamental law of congestion' (see Appendix A, Section 4.2.8). In practice, this relies on correctly controlling for exogenous factors such as background growth. Moreover, as the analysis focusses on a particular road types, these elasticities do not control for re-assignment of trips from other road types and hence the potential benefits arising from reduced congestion on these roads. The re-assignment effect can be estimated from the impact of a change in IH capacity on the demand for major urban roads; a negative response means that traffic is diverted away from major roads, most likely to the expanded highways. Duranton & Turner find such a negative effect of IH capacity on VKT measured on major urban roads (elasticity of -0.1). The implication for induced traffic, as understood in this review, is that the induced response to an increase in IH capacity would be smaller than reported because the measured VKT on the Interstate Highway includes an element of traffic re-assigned from other urban roads. The size of this effect will, however, depend on the share of re-assigned traffic in the IH traffic. The authors also quantify the impact of the starting level of congestion on induced demand and find a negative relationship, such that the higher the level the initial congestion, the smaller the proportionate increase in demand, for a given level of capacity expansion.

4.2.19. Hsu & Zhang (2014) apply a similar approach to Urban Employment Areas (UEAs) in Japan and obtain similar results, with values between 0.83 and 1.3, depending on the method used. These authors extend the Fundamental Law of Congestion in two ways. Firstly, they include a coverage effect, which consists of extending the length of existing routes or creating new routes. Secondly, they argue that increasing returns to scale can occur when lanes are expanded from single to multiple lanes, as there is more 'lane efficiency'.[34] Additional coverage results in more traffic travelling at lower speeds, while lane efficiency means more traffic can be accommodated at the same speed. These two effects are used to explain elasticities greater than one. In the empirical analysis, they find a coverage effect of 0.264 and a capacity effect (where lanes are expanded on the existing network) of 0.89. Although these authors only look at national expressways, between 9.4 and 12.4% of these were single lane over the study period. The empirical evidence presented in support of lane efficiency is, however, limited.

4.2.20. Pasidis (2017) determines elasticities for 545 Large Urban Zones (LUZ) in the EU28.[35] Elasticities for the study period are found to be in the range 0.7 to 1.0, with coverage and capacity effects of 0.3 and 0.83 respectively, similar to the results of Hsu & Zhang (2014). Pasidis (2017) finds a much smaller elasticity for urban zones with metro systems (0.2), than for those without (0.72).

4.2.21. Graham (2014) uses a different method (propensity scoring) on city level data in the US and finds an elasticity of 0.9, consistent with the above studies.[36]

[32] Duranton &Turner (2011), use planned interstate highway kilometres from the 1947 highway plan; 1898 railroad route kilometres; and the incidence of major expeditions of exploration between 1835 and 1850. Similar instruments are employed by Hsu & Zhang (2014) and Pasidis (2017). All these studies also determine elasticities using pooled Ordinary Least Squares (OLS) and fixed effects estimators.

[33] See Downs (1962), Duranton & Turner (2011). This definition assumes constant returns to scale in capacity expansion and, in utility terms, does not distinguish between the effect of lane-km from capacity expansion on existing networks or new roads. Hsu & Zhang (2014) extend this definition to include scale efficiencies from additional lanes. No improvement in travel times on a particular road type does not imply no welfare gains when all travel markets are considered.

[34] This could also be interpreted as the result of better signposting, road engineering etc.

[35] The author uses UNECE traffic data to determine highway VKT and the log sum of the length of Roman roads, the 15th century trade routes, the 1810 post routes and the 1870 railroads in each LUZ as an instrument for the number of highway lane km.

[36] The study focuses on methods and does not provide much detail on the application. Hence it is not clear if the vehicle miles travelled covered all routes or only freeway and arterial routes. We also note that the study by Schiff et al (2017) did not provide evidence on induced traffic from road capacity increases.

Additional European evidence

4.2.22. A study of the trunk road network in the Netherlands (van der Loop et al., 2016) used a regression approach to determine induced demand arising from additional capacity in the form of extra lanes added to the network at 150 locations, representing a 10% increase in overall network capacity. New capacity became available on road segments at different times over the 2000-2014 study period.[37] The percentage change in VKT with the capacity improvement was then estimated. Controlling for increases in background traffic (12%), using population, employment and car-ownership variables, the authors found 3% induced traffic on the trunk road network and an additional 1% traffic that had been reassigned from arterial roads. Given the capacity increase of 10%, this corresponds to an elasticity of 0.3. Since traffic on these main roads represents two thirds of all road traffic, this corresponds to an overall elasticity of 0.2. However, the authors also note that difference in time of day and location are smoothed out in these estimates.

4.2.23. Finally, Weis & Axhausen (2009) provide additional relevant evidence from their study on accessibility at the municipality level in Switzerland. Travel demand in this study covers all modes, not just road, and accessibility, constructed as a weighted sum of population and travel time, can be influenced by other policy measures than road capacity increases. They find that a 10% improvement in accessibility would result in a 4% increase in the number of trips made but the length of trip would increase almost proportionately (i.e. also by 10%).

LITERATURE REVIEW STUDIES

4.2.24. The review papers provide a useful overview of quantitative studies published in 2006 or earlier. Currie and Delbosc (2010) report a range of studies published in or before 2002.[38] These studies determine SR and LR elasticities for a range of geographical scales (facility, county, state and national) for new roads, road widening and non-specific interventions, predominantly using data from the US. The SR elasticities range from 0 to 0.68 and the LR elasticities from 0.29 to 1.1. A similar table is presented by Noland and Hanson (2013). Their table also contains more recent studies, which are reported on separately in the next section. These authors include two studies that look at project level investments and account for indirect effects i.e. induced demand due to land-use development associated with the transport project. These studies found SR elasticities of 0.24 (Cervero, 2003) and 0.29 (Strathman et al., 2000) and indirect elasticities of 0.1 and 0.033 respectively. Again, the evidence base was US focused. For studies published prior to 2007, Noland and Hansen (2013) report SR elasticities in range 0.19 to 0.6 and LR elasticities of 0.3 to 1.0.

4.2.25. The review by Milam et al. (2017) is concerned with transport analysis in California and reports on a subset of studies covered in Noland and Hansen (2013). Milam et al. (2017) include only the values denoted as indirect elasticities by Noland and Hansen (0.1 SR, 0.39 LR). Similarly, the review by Litman (2014), although wide ranging, does not add any additional results relevant to this study that are not reported elsewhere.

4.2.26. Elliot (2016) does not provide elasticities but summarises findings from the SACTRA report (1994) and the CPRE report (2006).[39] He notes that SACTRA (1994) found that '*the average traffic flow on 151 improved roads was 10.4% higher than forecasts which omitted induced traffic, and 16.4% higher than forecast on 85 alternative routes that improvements had been intended to relieve. In a dozen more detailed case studies the measured increase in traffic ranged from 9% to 44% in the short run, and 20% to 178% in the longer run.*' Elliot also reports the CPRE (2006) conclusion that '…*the new roads did significantly reduce the town centre traffic levels. However, these reductions are not as great as originally forecast and there has subsequently been regrowth in traffic levels on the bypassed roads. The net effect in combination with the new road is generally a considerable overall increase in traffic.'*

MODELLING STUDIES

4.2.27. Three modelling studies were reviewed. They all covered investments in metropolitan areas. The modelling approaches differentiated between background, reassigned traffic and induced traffic, but did not provide information on relative magnitude of the capacity increase for which the induced traffic was calculated.

4.2.28. Naess et al. (2012) applied two models – one that accounted for induced traffic and one that did not – to a 1650m length of new urban dual-carriageway in a congested corridor in the Copenhagen area. They found

[37] Dummy variables were used to take account of this in the analysis.

[38] The authors cite Schiffer et al (2005) as the source of this material.

[39] The SACTRA report covers a range of UK evidence. The CPRE report looked at the A27, A34 and M65, as well as schemes on the A5, A6, A41, A43, A46, A66, A500 and A1033.

that 5 per cent of traffic flows on the main link in the short term were attributable to induced traffic. Kang et al (2009) modelled the impact of two infrastructure investments in the Hamilton metropolitan area in Canada, one in 1997 and one in 2007, on the percentage change in car trips in the am peak from 2001 to 2030. Most of the change was a result of background traffic growth (19.3 per cent), with only a small proportion of induced trips (0.7 per cent) and even less re-assignment. These models did not include land-use effects. It is not clear that distance effects were included in the induced traffic measures.

Using a land-use and transport integrated model, Börjesson et al (2014) examined the effect on traffic (VKT) in the Stockholm city region to 2030 of changes in land-use development patterns as a result of transport investment. They considered three scenarios in which a single investment, a Stockholm Bypass, was made in all cases but a different pattern of land use development was assumed for each. They found an increase in VKT of 3.68% when expected existing land-use patterns (no-build scenario) were implemented, increasing to 3.84% when land-use patterns were adjusted for the transport investment (build scenario). These results indicate that additional induced traffic from land-use developments that can be attributed to the transport investment (0.16%) is much smaller than other short-run sources of induced traffic (3.68%) on the expanded transport network. The authors do not report expected traffic growth over the modelling period but calculate a population increase of 28% in the region.

Table 4-2 Summary information for papers reviewed[40]

Study no	Authors	Evidence type	Induced demand measure	Supply measure	Output	Time period	Geography / Scale	Induced traffic
6	Börjesson, et al. (2014)	model	VKT (all road types - zones)	fixed infrastructure projects	% change VKT (build/no-build)	2006-2030	Stockholm city region	3.68% increase under expected land-use patterns 3.84% when land-use patterns adjusted for transport investment
9	Concas (2013)	econometric	VKT (al	productive capital expenditure	elasticity	1982-2005	state level (US)	SR:0.041, LR 0.237
11	Currie and Delbosc (2010)	review			elasticity	various	various	Based on Schiffer (2005), also review: 1) SR average 0.35, range 0 - 0.68 2) LR average 0.69, range 0.29 - 1.1
12	Davies (2015)	case study	AADT (measured on main link only)	various fixed infrastructure, different road types (7)	% change AADT (build/no-build)	1990s-2013	7 projects (Queensland)	17 to 38% increase in AADT in 2 years average across projects. Then return to pre-construction growth rates.
13	Elliott (2016)	review	traffic	various	% traffic change	various	Mainly UK projects	Reports SACTRA (1994), CPRE (2006)
19	Gonzalez and Marrero (2012)	econometric	VKT (all roads)	lane-km	elasticity	1998-2006	16 regions, various sizes (Spain)	SR 0.1135 to 0.1742 LR 0.2671 and 0.3052 (ranges due to different levels of instrumentation)
20	Graham (2014)	econometric	VMT (all roads)	lane-miles	elasticity	1982-2007	city level (US)	0.9
22	Hymel et al. (2010)	econometric	VMT (all roads)	lane-miles (urban), road length/square-mile (non-urban)	elasticity	1966-2004	state level (US)	SR 0.032, LR 0.16
27	Kang et al. (2009)	model	trips (all roads)	2 fixed projects	% change in car trips cf baseline, am peak hour	2001-2030	single MSA (Canada)	19.3% traffic increase due to population growth; 0.7% induced traffic
46	Milam et al. (2017)	review	VMT	capacity increase (secondary	elasticity	1973- 2003	various (US)	Findings for 5 US studies: SR: 0.1 to 0.6

[40] Notes: VMT = vehicle miles travelled, VKT = vehicle kms travelled, SR = short-run, LR = long-run, MSA = Metropolitan Statistical Area, IH = Interstate Highways. Wrt = with respect to.

Study no	Authors	Evidence type	Induced demand measure	Supply measure	Output	Time period	Geography / Scale	Induced traffic
				reporting, so not clear)				LR: 0.4 to 1.03
48	Naess et al. (2012)	model	AADT	new urban dual carriageway (1650m)	% traffic difference between model with and without induced demand	opening year only	main link (Denmark)	5% increase on main link including induced demand
50	Nicolaisen and Næss (2015)	case study	AADT	20 road projects in UK and 15 in Denmark. These were limited to projects where do-nothing could be empirically established.	% difference in observed and forecast Do-nothing traffic volumes	projects completed between 1985 and 2010	Projects (UK/Denmark)	Compares observed and forecast Do-nothing
61	Schiff et al. (2017)	econometric	AADT	Busway	%change in vehicles relative to counterfactual	2008-2015	project (New Zealand)	Not directly relevant as public transport investment
63	van der Loop et al. (2016)	econometric	VKT	additional lanes at 150 locations on trunk road network (+10% capacity). Modelled as dummy for lane in place or not, at each observation time and place	% increase in VMT, elasticity	2000-2014	trunk road network, all road network (Netherlands)	4% increase in workday VKT from 2000 to 2014 1% of this was due to reassignment, 3% induced demand. This also represents 2% of traffic on all roads (because traffic on main roads is 2/3 of all traffic). Elasticity of 0.3 for VMT on trunk network, 0.2 on all roads. (Background growth 12%).
65	Weis and Axhausen (2009)	econometric	trips, trip-length (all modes)	accessibility, based on population and travel time between municipalities	elasticity	1974-2005	individual (Switzerland)	Elasticity of demand (trips) wrt accessibility: 0.4. Elasticity of demand (trip-length) wrt accessibility: 0.89 to 1.14
70	Rohr et al. (2012)	model/case study	car trips (+ other modes) for commute and other travel	M60 motorway box scheme	% trips (screenline approach), also reports elasticities (tours and km) wrt to time and cost changes more generally	Before (1999)/After (2003) screenline data, plus household survey data	Manchester Motorway Box region (UK)	15-17% increase in car trips crossing screenlines. Small % of this due to population and employment changes (related to infrastructure?): 2-3.5% 4% mode shift 9% destination shift 10% increase average commute journey length
72	Duranton and	econometric	VKT	lane miles (major	elasticity	1983-2003	MSA level (US)	Interstate highways: 0.73 to 1.39

Study no	Authors	Evidence type	Induced demand measure	Supply measure	Output	Time period	Geography / Scale	Induced traffic
	Turner (2011)			urban roads and highways)				(depending on method). Author preferred value: 1.03 Other major urban roads (excludes local roads)
74	Litman (2017)	review	various	various	various	various	various	Covered in other studies reviewed
75	Noland (2001)	econometric	VMT	lane miles	elasticity	1984-1996	state level (US)	All road types (lagged VMT): 0.119 (SR), 0.36 (LR) Higher values when differentiate by road type: For lagged VMT model: 0.3-0.6 (SR), 0.7-1.0 (LR)
76	Noland and Hanson (2013)	review	mainly VMT	mainly lane-km	elasticity	various	various	Covered in other studies reviewed or excluded on publication date.
78	Qing (2011)	econometric	VMT	lane miles	elasticity	2001-2008	state level (US)	0.066 (SR), 0.26 (LR)
79	Sloman et al. (2017)	case study	AADT	individual projects (mix of bypass, widening, ..)	% increase in traffic over background (screenline approach)	1997-2015	UK, project	For 8/9 schemes, using screenline approach, traffic growth higher than background, mostly by 5-10%. For M25 scheme 20%. Reports evidence of induced demand using screenline method for schemes assessed: SR average 7%, LR average 47%. Not clear how LR average has been obtained.
82	Hsu and Zhang (2014)	econometric	VKT	Lane km, length of road network	elasticity	data from 1990, 1994, 1997, 1999, and 2005	MSA level (Japan)	Elasticity wrt to lane km: 1.02 (OLS), 1.24-1.3 (IV road network plan), 0.83 (IV rail network) If separate out road length from total lane-km; Elasticity wrt lane km: 0.89, wrt to road length: 0.26.
83	Rentziou et al (2012)	econometric	VMT	lane miles	elasticity	1998-2008	state level (US)	rural roads: 0.244 (IH) urban roads: range over road types 0.272 to 0.531 (IH) Total VMT: 0.086 wrt total rural lane miles, 0.267 wrt total urban lane miles
84	Pasidis (2017)	econometric	VKT	Lane km, length of road network	elasticity	1985, 1995, 2005	EU28 LUZ (large urban zones)	range of SR estimates 0.7 to 0.1 (method dependent) Elasticities smaller for cities with metros (0.2) Decomposing coverage and capacity

Study no	Authors	Evidence type	Induced demand measure	Supply measure	Output	Time period	Geography / Scale	Induced traffic
								effects, elasticity wrt total length:0.3, wrt capacity(AADT): 0.83

4.3 DISCUSSION OF FACTORS INFLUENCING THE FINDINGS

DEFINITIONS OF INDUCED TRAVEL

4.3.1. The definition of induced demand was discussed at length in Section 2.1. However it is important to understand the definitions used in the studies reviewed as this will have an impact on the size of the reported induced demand effects and any subsequent welfare analysis.

4.3.2. The focus of this review was induced travel as a result of road capacity expansion so it is not surprising that most of the studies reviewed analyse induced travel in relation to road capacity expansion only. The exception is Weis & Axhausen (2009) who include additional demand for transport services directly caused by improving travel conditions.

4.3.3. A commonly quoted definition is that from Noland and Lem (2002) that induced travel is "the increase in vehicle miles [kilometres] of travel attributable to any transportation infrastructure project that increases capacity". That the new traffic attracted by a capacity expansion is a result of reduced travel times is also widely expressed. Milam et al. (2017) define it as "the additional travel that occurs when the cost is lower (e.g., as a result of a capacity expansion that reduces travel times), that is, the additional travel that is induced by the lower costs that result from capacity expansion". Hymel et al. (2010) also distinguish two types of induced travel: that arising from new roads that improve access to locations in undeveloped areas; and from increased capacity in congested urban areas.

4.3.4. Some authors consider induced demand from the perspective of the Fundamental Law of Congestion. This says that, on congested roads, the reduced travel times resulting from an increase in road capacity attracts traffic that was previously deterred, potentially leaving the routes as congested as they were before, i.e. an expansion in highway capacity results in a proportionate increase in driving. This additional traffic (or latent demand) previously used alternative routes or modes, travelled at different times or did not travel at all. Of course, if the traffic is diverted from other routes, you would expect decreases in congestion elsewhere.

4.3.5. The above definitions do not specifically define the area or timescale over which induced travel is defined and do not necessarily exclude re-assigned traffic. Several authors do explicitly exclude shifts in the time of day or location. Naess et al. (2012), for example, exclude change in time and location of travel within same transport corridor. What is included as induced travel in the analysis largely depends on the data used and the focus of the analysis. Studies that use annual average daily traffic flows, or VKT derived from these data do not include time of day effects in their measure of induced demand. The types of roads included in the analysis and the scale at which calculations are made will also determine induced travel estimates.

METHODOLOGICAL APPROACHES

4.3.6. Four categories of papers were included in this review: case studies, econometric studies, modelling studies and literature reviews. Case studies, econometric studies and modelling studies represent distinct methodological approaches. These are also covered in the review papers, although these mainly report on econometric studies.

4.3.7. Econometric studies almost exclusively report induced demand effects in terms of the elasticity of VKT with respect to road capacity expansion. VKT is usually derived from traffic flow and network length data. Using VKT means that changes in journey length, either by changing route or destination are included in the measure as well as additional trips, assuming appropriate network coverage. However, if traffic and road capacity data for only one road type is used in the analysis, then the induced travel would include the VKT from drivers changing route to this road type e.g. SRN or LRN (these trips would have been made anyway). In our terminology, this re-assigned traffic is not induced demand which is overestimated.

4.3.8. While most econometric studies reviewed estimate the same form of equation (Equation(1), Section 4.2), they differ in terms of the approach used to control for background traffic growth and the estimation method. Most studies control for what are expected to be the main drivers of background traffic growth: population, a measure of income or GDP and fuel price. In general, studies that include vehicle stock in the estimation approach return lower elasticities. These studies estimate induced demand effects over all road types at a state or regional level. Hymel et al. (2010) generated smaller elasticities using the same data as Noland (2001), who did not include vehicle stock. The two studies also used different estimation techniques.

4.3.9. Different forms of estimation and instrumentation are used to control for different potential sources of bias arising from the data and variables used, including endogeneity and omitted variable bias, among other things. One of the main concerns is that there is a two-way relationship between VKT and road capacity. Demand may be expanded in response to new road infrastructure (the issue that we are focussed on in this study), but also road expansion is likely to be linked to demand, i.e. road investment is likely to occur in areas with high demand. It is therefore difficult to isolate the effect of induced traffic that results from the capacity expansion.

4.3.10. Duranton and Turner (2011) are critical of the approach to instrumentation used in earlier studies as being insufficient to fully account for endogeneity and employ historical road and railway planned development as an instrument for road capacity expansion to identify the causal effect. Their paper and others using the same approach estimate elasticities for urban areas on particular road types. The elasticity estimates they obtain using other methods without instrumentation are of a similar order of magnitude.

4.3.11. Case studies tend to use observations of traffic flows from before and after the implementation of a road improvement scheme. Measured traffic flows may be converted to VKT, as was the case for econometric studies but isolating the effect of the scheme is potentially more challenging than determining aggregate relationships, particularly in the long run. Case studies mainly report percentage changes in trips or traffic flows as a result of a particular transport project and control for reassigned traffic and background traffic so that the resulting change represents induced trips, for example using a screenline approach. It is not always clear how this is done. Moreover, this approach does not differentiate between different types of induced travel, e.g. as a result of increases in travel or from changes in destination or journey length. The study of the Manchester Motorway Box (Rohr et al., 2012) overcomes this issue by using a model in conjunction with the before and after survey data.

4.3.12. Models can take account of changes in destination and trip length. They can also include land-use development patterns and the impact of this on transport demand. Models do not provide empirical evidence, however, and rely on assumptions. Transport models may be well calibrated against observations but this may not be the case for longer term land-use effects, for which data are more difficult to measure.

TYPES OF INTERVENTION COVERED AND AREA OF INTEREST

4.3.13. Econometric methods provide evidence on non-specific interventions (increases in lane-km or length of road network) and not specific project interventions.[41] Although they distinguish between urban and non-urban roads in the network, econometric studies are very aggregate and generally look at impacts on quite a broad network scale (i.e. Interstate Highway network within an MSA or at the state level). The non-specific nature of the interventions means that the induced demand effects are reported as elasticities and not related to actual travel that would result from particular road building. Moreover, a lane-km from a road widening and a lane-km from a new road are generally considered to have the same effect on traffic volumes (VKT). Hsu and Zhang (2014) separate out coverage (increased road length only) and lane-expansion effects.

4.3.14. Where different road types are considered separately, the cross-effects of expansion of one road type on the demand for another road type should provide information on the size of the re-assignment effect. However, on congested road networks this may be masked if there is suppressed demand for all road types. The traffic that diverts from the arterial route to a highway due to increased highway capacity may be replaced by new traffic on the arterial route that comes from another source and these effects cannot be distinguished in the VKT measure.

4.3.15. Case studies provide evidence at a project level but it what the project represents in terms of network capacity expansion or over what area this is being measured is often not reported. This information may be available from modelling studies but is not generally reported. This makes it difficult to compare the induced demand effects reported in the different types of studies. Understanding the percentage increase in capacity for which a percentage increase in traffic is attributed to induced travel would allow some comparison between case-study evidence and between case study and econometric and model results. Moreover, in the long-run traffic growth related to land use changes may be due to transfers of residence, businesses etc. from other areas. Whether these are included as induced traffic depends on the geographical area covered in the appraisal.

SOURCES OF EVIDENCE AND TRANSFERABILITY

4.3.16. It is expected that UK and European data would be more relevant to this study (compared to data from the US, Japan or other countries), as these have the most similar road and public transport networks. Most UK and European evidence is from case studies and models. Case studies are project specific and, without a wider

[41] The exception is Cervero (2003) reported in the review papers. This study considered 24 highway projects at the county level in California.

body of evidence it is difficult to generalise. van der Loop et al. (2016) provides the only European evidence on a national road network.

4.3.17. Many of the studies reviewed and the resulting elasticities are derived from US data, possibly because of data availability. 74 per cent of US population live in urban areas. The urban population is also 74 per cent in the UK but urban areas are not really comparable between the two countries. There is a huge range in terms of the MSA population in the US, with 50 having populations in excess of 1 million.[42] There are also differences in the alternative modes available to car. Most analyses either did not control for modal shift or include bus as the only alternative. Train was not considered as an alternative in the studies reviewed, while Pasidis (2017) found the presence of a metro to be an important determinant of induced travel in European cities.

4.3.18. It is not possible to draw any conclusions on the impact of the age of data on the evidence. The studies used data covering a range of periods, from the 1960s to 2015. More recent data was used for case studies. Differences are more likely to be attributable to methodology, type of intervention and scale.

4.4 QUALITY OF THE EVIDENCE

4.4.1. Econometric analysis provides a robust framework for deriving associations between variables using empirical data. A high proportion of studies in this review use econometric techniques and most of these have been published in peer-review journals. However, the quality of the evidence is limited for two reasons. Firstly, they only consider non-specific changes in road capacity, rather than specific project interventions and the sources of induced traffic are rarely considered or quantified (mode shift, new trips, land-development, etc). Secondly, despite using similar (or even identical) data, different results are often obtained from different studies. These differences cannot easily be clearly identified and quantified as a function of methodology and geography or time scale. In particular, it is difficult to understand the impact on the estimates of the methods used to control for background growth and endogeneity bias.

4.4.2. Four studies reporting case study evidence were reviewed. For only one of these (Rohr et al., 2012) was data collected before and after implementation of the road improvement scheme, with the specific aim of quantifying the induced demand effect. Other studies use data from available sources (e.g. the DfT POPE database) to determine induced demand. While this is a sensible approach, given the cost of collecting project related data, the details of the analysis undertaken to control for background traffic growth and re-assigned traffic need to be explicit. Moreover, although the percentage increase relative to the baseline that induced traffic represents is important for a particular project, in terms of the comparability of evidence for this review, it would be useful for studies to also report background traffic growth and the percentage increase in capacity on the network of interest. Only Davies (2015) reports these effects.

4.4.3. Modelling studies do not provide empirical evidence on induced demand. They were included in this review to compare how models that explicitly account for induced demand compare with observed results. The main limitation is not the model quality but the difficulty of making meaningful comparisons between the model outputs and empirical evidence.

4.4.4. The review papers were mainly a useful, if uncritical, source of information on earlier publications.

4.4.5. An important issue relating to quality is publication bias. It is expected that studies that find induced demand are more likely to be published than those that do not find any effect. Thus the estimates are likely to be overestimates.

[42] Sources: US Census (2014), Hsu & Zhang (2014), OECD statistics.

5 DISCUSSION OF EVIDENCE AND CONCLUSIONS

In this section we discuss the main findings from the studies reviewed in this report and then draw out the overall implications of the evidence for RIS2, including gaps in the current evidence base.

5.1 WHAT ARE THE KEY FINDINGS AND WHAT DO THEY MEAN FOR RIS2?

5.1.1. Much of the evidence reviewed in this report comes from econometric studies, with a smaller body of evidence from case studies and models.

The evidence from econometric studies is varied but there are some consistent findings

5.1.2. Elasticities of demand with respect to capacity expansion provide a measure of the induced demand effect that can easily be derived from econometric analysis. Elasticities represent the percentage change in traffic (VKT) relative to a percentage change in road capacity. A wide range of elasticity values are, however, reported in the literature. Specifically we find that:

- LR estimates of induced demand are larger than SR estimates. This is consistent with the expectation that there are more sources of induced demand in the long run when changes in employment, residential location and land-use may play a role than in the short run. Of course, it is not clear whether these changes in employment and residential location are transfers from other areas, which may see reductions in travel. Short run estimates range from 0.03 to 0.6, long run estimates from 0.16 to 1.39.
- Studies that differentiate between urban and non-urban areas find a larger induced demand effect in urban areas (Rentziou et al., 2012, Duranton & Turner, 2011). Urban areas are expected to have high initial levels of congestion and potentially higher levels of suppressed demand. However, only one study (Pasidis, 2017) analyses the effect of a metro system on road traffic and finds a much smaller induced demand effect in cities with metro systems. The implication is that cities with good public transport provision may have less suppressed demand for road travel.
- Induced demand elasticities that are close to one are associated with studies that estimate long-run elasticities for specific road types, particularly in large metropolitan areas, outside of the UK. They also mainly use the same methodological approach (Duranton & Turner, 2011, Hsu & Zhang, 2014, Pasidis, 2017). As they focus on particular road types, the demand response reported in these studies generally include re-assignment effects and is larger than the induced demand response.
- There is no recent econometric evidence on project level investment. van der Loop et al. (2016), consider the overall impact on the network of 150 separate capacity improvements. The review studies report short-run elasticities of 0.24 (Cervero, 2003) and 0.29 (Strathman et al., 2000).
- There are clear differences in the magnitude of long run elasticities estimated using different methodological approaches. These differences cannot be fully explained by the geographical scale at which the elasticities are estimated or the type of roads included in the analysis. One explanation is that some studies suffer from endogeneity; while induced traffic is the VKT response to increased capacity, some of the observed increases in road capacity may themselves have been as a result of increases in VKT. Not fully controlling for this latter effect may lead to smaller elasticity estimates. Another possibility is that approaches estimating smaller elasticities control differently for the background traffic component of VKT.

It is difficult to compare the econometric evidence with the evidence from case studies and modelling

5.1.3. The evidence from case studies and modelling is reported as percentage changes in traffic relative to the baseline, having controlled in some way for background traffic growth and reassigned traffic. These percentage changes are not related to a corresponding percentage change in capacity and may also be measured in numbers of vehicles rather than vehicle-kilometres. This makes them difficult to compare with the elasticities reported in econometric studies.

- Case studies reported a wide range of short-run percentage changes in traffic flows (5 % to 38%). These cover a range of different projects. Large percentage changes are reported for improvements to highly congested routes (Davies, 2015) or roads that fall within large metropolitan areas, such as the M25 (Sloman et al, 2017).[43]

[43] We note that this is our categorisation using the terminology of some econometric studies.

- Modelling studies reporting at the city region scale find smaller percentage changes in traffic flows due to induced traffic (0.7% to 3.84%), compared with 5 per cent on a main road link.

5.1.4. Based on the evidence from the different study types, we identify some broad, overall findings.

More induced traffic is associated with road capacity increases where there is a high level of congestion and suppressed demand

5.1.5. There is econometric and case study evidence that indicates the induced demand effect is greater when there is a high level of congestion. Much of this evidence is from large metropolitan areas, where congestion and suppressed demand are expected to be present. The range of values reported in the evidence makes it difficult to quantify for RIS2. However, most studies that report elasticities indicate that a 10 per cent increase in capacity would result in at least 5 per cent induced traffic. The starting level of congestion is important for the size of the effect. However, the empirical evidence does not really quantify this beyond differentiating between urban and non-urban settings.

A smaller induced demand effect is associated with capacity changes at an aggregate scale or for changes that increase accessibility.

5.1.6. Studies that estimate elasticities of demand with respect to road capacity considering all road types (and therefore controlling for reassignment effects) at the state or regional level find smaller induced demand effects, such that a 10 per cent increase in capacity would result in induced demand in the range 1 to 4 per cent (e.g. Hymel et al, 2010, Gonzales & Marrero, 2012). For the trunk road network in the Netherlands, an elasticity of 0.2 is estimated (van der Loop et al., 2016). Where the impact of road capacity that adds to the length of the road network is distinguished from lane capacity increases for the existing network (Hsu & Zhang, 2014, Pasidis, 2017), the former can be interpreted as an accessibility effect. This is associated with a smaller elasticity (approx. 0.3).

The size of the induced demand effect relative to background traffic growth in the long run is not clear

5.1.7. This could be important if road building is designed to cope with future expected growth rather than to relieve congestion and is discussed further in Appendix A. van der Loop et al. (2016) find a 3 per cent induced demand effect (corresponding to an elasticity of 0.2) compared to 12 per cent background traffic growth over a 14 year period. Modelling studies covering long run changes also find small induced demand effects relative to background growth (Kang et al. (2009) estimate 0.7 percent induced traffic and 19.3 per cent background growth). However, many studies either focus on the short run or do not report the background effect in addition to the induced demand effect.

5.1.8. With the exception of models, the evidence presented in this review is based on observed traffic, from which the induced traffic component is then derived in some way. The observed traffic includes background growth as well as re-assigned traffic and the methodology used to control for these two types of traffic will have an impact on the resulting estimation of induced demand and need to be clearly explained.

Recent evidence from the UK and Europe is consistent with the findings of SACTRA 1994

5.1.9. The evidence they reviewed included before and after studies from the UK (including London) and Amsterdam, which showed that traffic level increases on new routes were not offset by corresponding reductions in traffic on equivalent unimproved routes. This was consistent with the existence of induced traffic but it was not possible to show the sources or size of effect. The report also highlighted the potential difficulties for research on induced demand such as isolating a statistically significant effect due to one factor, causality, establishing suitable controls and the problem of comparing evidence drawn from different sources.

5.2 EVIDENCE GAPS

There is limited evidence on the sources of induced traffic

5.2.1. Using a combination of case-study and modelling approaches, Rohr et al. (2012) were able to quantify the share of induced car trips that resulted from destination changes and mode shift for the Manchester Motorway Box with change in destination the more important source. The Weis & Axhausen (2009) evidence suggests that increases in journey length may be a more important source of induced traffic than additional trips, although this is not limited to road traffic. Duranton & Turner (2011) is the only econometric study that analyses the possible sources of induced demand resulting from road capacity expansion. Using US data they find that the demand response is mainly due to new travel. However, they are not able to distinguish between additional trips and increased trip length. Trucks trips are found to account for almost 30% of additional VKT, changes in annual household travel behaviour for between 9 and 39%, route switching for 10% and migration

6%. While these authors find a negligible impact of modal shift from bus, Pasidis (2017) suggests that cities with metro systems experience less induced demand.

5.2.2. In their review, Noland & Hansen (2013) report evidence from two studies (Cervero, 2003, Strathman et al., 2000) that estimate indirect elasticities for the induced demand due to land-use development associated with a transport project investment of 0.1 and 0.033 respectively. More recent econometric studies do not explicitly consider land-use effects. Börjesson et al., 2014 find only a small indirect effect on modelled traffic from such land-use changes (0.16%) compared with other sources of induced demand (3.68%).

5.2.3. Understanding the sources of induced demand is important for the economic appraisal of transport projects, as there may be different benefits on different travel markets as a result of capacity expansion. The implication of the sources of induced traffic for transport appraisal is discussed in detail in Appendix A.

There is very little empirical evidence on induced demand for the UK or even for European countries.

5.2.4. Most econometric studies have focused on US with some additional data from Japan and Europe. It is not clear how transferable this evidence is to the UK, given the scale and scope of the analysis. There is some evidence from case studies, including one study using POPE data, and modelling studies from the UK and Europe but these are not easily comparable.

5.3 CONCLUSIONS AND FURTHER WORK

5.3.1. The evidence reviewed in this study supports the findings of the SACTRA (1994) report that induced traffic does exist and may be significant in some situations. There remain wide variations in the quantitative evidence that make it difficult to draw conclusions as to the magnitude of the impact of induced demand on road capacity improvements made to the Strategic Road Network. However, we draw some tentative conclusions:

- Findings for state level road networks in the US and the national Dutch network indicate an elasticity of around 0.2 across the whole road network, i.e. 10% increase in road capacity could lead to 2% induced demand on the network.
- Induced demand is likely to be higher for capacity improvements in urban areas or on highly congested routes. There is little evidence that extreme levels of induced demand would therefore occur on the Strategic Road Network.
- It is not clear whether the available case study evidence supports the econometric results because the two types of evidence are presented differently.
- The evidence on the existence of induced demand means that it needs to be properly accounted for in appraisal of capacity improvements to the Strategic Road Network.[44] The demand impacts on other travel markets need to be quantified as part of this appraisal but there is a lack of evidence on the source of the induced demand for road travel and the size of these impacts.

5.3.2. There are a number of areas that would benefit from further work.

- Case study evidence is limited. Although there are major difficulties in designing a study to collect robust data (Rohr et al., 2012), it would be useful to be able to generalise more from specific case study examples to different types of road improvements. These could be categorised by scheme type but also by area type and geographical scale. More data related to the scale of the improvement relative to the network of interest would also be needed.
- The evidence base on induced travel is mainly from outside the UK. Some econometric evidence, in particular, mainly relates to increases in road capacity in large metropolitan areas, which may not be directly relevant to road building in the UK. Appropriate econometric analysis based on UK data would provide a useful addition to the evidence base. This could potentially make use of existing data from POPE or the National Travel Survey.

5.3.3. There is very little evidence on the sources of induced traffic in the short or long run. These are important for transport appraisal, where induced road traffic may come from other modes or result from economic growth due to land-use development associated with the transport investment. There may also be additional traffic resulting from changes in land use such that residences or business locations have been transferred from other areas. Determining how best to measure these effects is itself an area for research. The geographical

[44]Modelling of VDM is out of scope of this review and the relevant DfT guidance is TAG Unit M2: https://www.gov.uk/government/publications/webtag-tag-unit-m2-variable-demand-modelling-march-2017.

scale for measurement and appraisal becomes important in determining whether these are included as induced traffic.

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Appendix A

IMPLICATIONS FOR TRANSPORT APPRAISAL

A.1 INTRODUCTION

In this chapter we set out the theory for transport appraisal with induced road traffic. This then sets the framework within which we discuss issues raised in the evidence review associated with cases of total filling-up of new road capacity (perfectly elastic demand), impacts on other modes, changes in land use, and benefits in the rest of the economy. The core of this framework is well developed, and we therefore draw substantially from Mackie (1996).[45]

A.2 USER BENEFITS

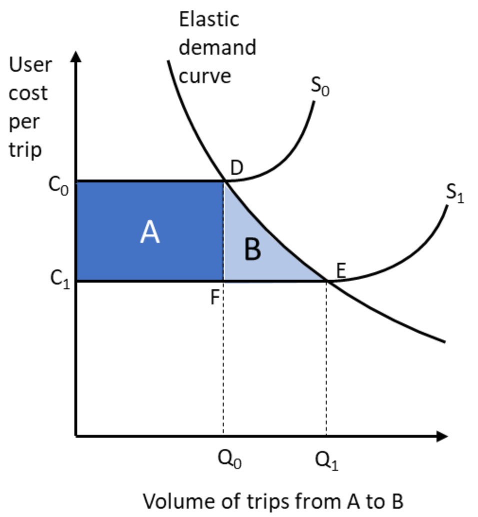
The starting point is that road transport is like any other economic good.[46] As the price of transport, modelled as a generalised cost, falls the demand for transport increases. This is illustrated in Figure A-1 by the downward sloping demand curve. The network performance in the 'Do Minimum' scenario is given by the supply curve S_0. A road investment leads to a downward and outward shift in the supply curve to the 'Do Something' curve given by S_1. Actual traffic volumes are determined where the demand and supply curves intersect. The traffic volumes are Q_0 in the Do Minimum and Q_1 in the Do Something so we can see that the road investment induces Q_1-Q_0 trips onto the road network.

The aggregate benefit to travellers between A and B due to the fall in cost per trips is C_0DFC_1. This is depicted by Areas A and B in Figure A-1. The benefit to existing users is Area A, and that to the induced traffic is Area B. This is the consumer surplus – the benefit to consumers as a result of the change in generalised cost of travel. It is often referred to as user benefits in a transport context.

If the cost changes are not large then the demand curve can be approximated as linear. This gives rise to the 'Rule of a Half' formula and is embodied in WebTAG (see TAG Unit A1.3[47]):

$$User\ Benefits = 0.5\ (C_0 - C_1)(Q_0 + Q_1)$$

Figure A-1 User benefits



In the situation depicted in Figure A-1 the road network is uncongested in both the Do Minimum and the Do Something. If however the networks are congested, that is we are operating on the upward sloping part of the supply curves, then induced traffic imposes a congestion cost on the existing traffic. This is shown in Figure A-2. Once again the benefit from the transport improvement is given by the sum of Areas A and B, and the Rule of Half formula applies (noting the cost difference is C_2-C_0). What is interesting in this example though is

[45] Mackie, P.J. (1996) Induced traffic and economic appraisal. *Transportation* **23** pp103-119.

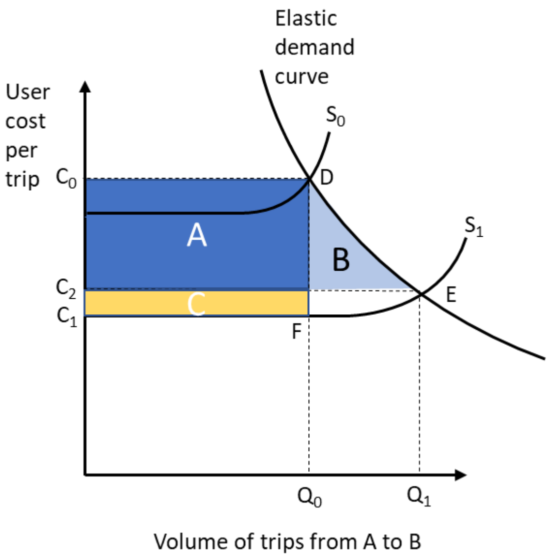
[46] Noting the demand for travel is a derived demand that is associated with demand to undertake activities at the destination.

[47] DfT (2017a) TAG Unit A1.3 User and Provider Impacts. March 2017. Department for Transport. https://www.gov.uk/government/publications/webtag-tag-unit-a1-3-user-and-provider-impacts-march-2017

that, due to network conditions, the congestion costs imposed by the induced traffic erodes some of the user benefit that would have occurred to the existing traffic. This erosion of benefit is given by Area C.

There is, however, no need to calculate Area C during an economic appraisal, as our interest is in the user benefit delivered by the transport improvement (the sum of Areas A and B which is captured in the Rule of Half). It is however important that the modelling framework adopted can model the congestion cost imposed by the induced traffic on the existing traffic. This is because the modelling framework ultimately drives the economic appraisal. This requires a model that can capture changes in both demand and congestion costs. Moreover, when networks are congested the error associated with an incorrect modelling of demand and congestion can be very large (see for example Coombe, 1995 for some case studies of congested urban areas).

Figure A-2 The erosion of user benefits to existing traffic due to induced traffic



A.3 GROWTH OVER TIME AND SUPPRESSED DEMAND

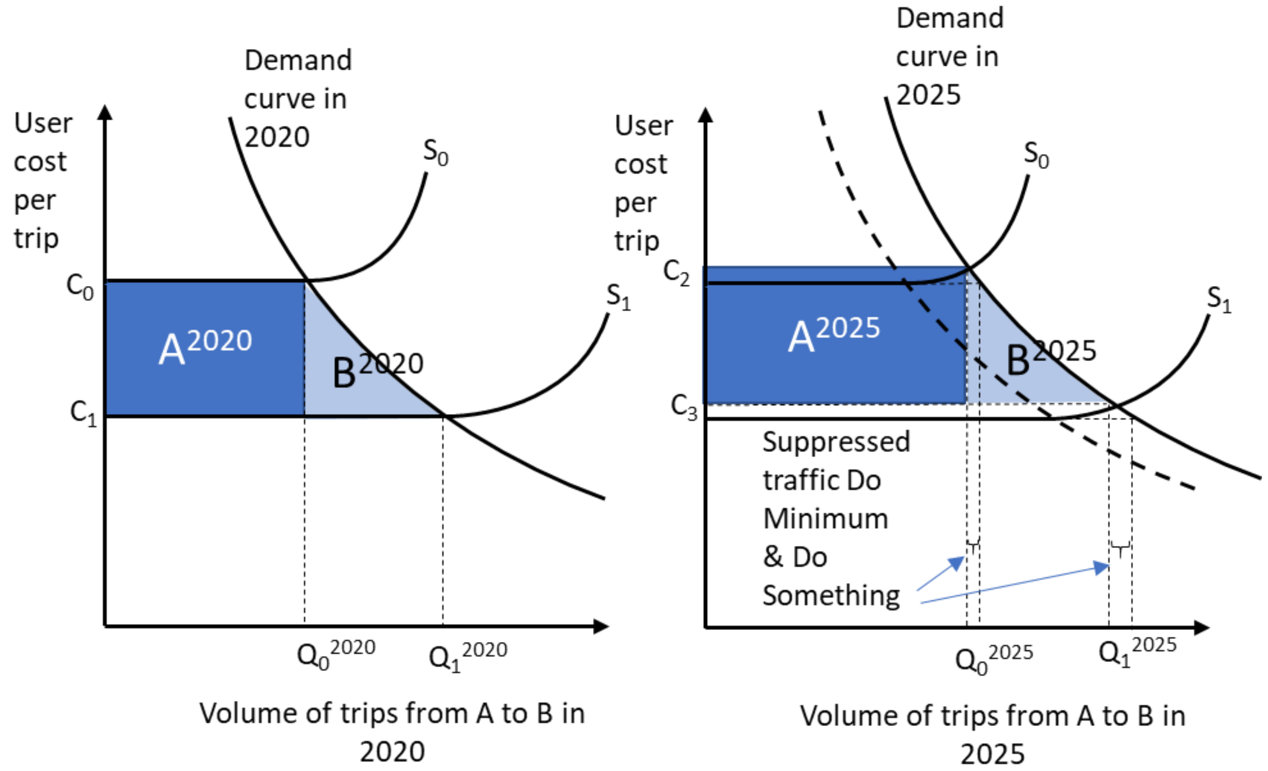
Suppressed demand and induced traffic are effectively two sides of the same coin. If prices fall, the demand for a good increases (this is the induced traffic). If prices rise the demand for a good decreases (this is the suppressed traffic). That is induced traffic occurs when the generalised cost for travel decreases. If the generalised cost for travel increases, then we see suppressed travel, which will become induced travel if the generalised cost decreases.

There are two circumstances in which traffic may be 'suppressed'. Firstly transport policy may increase the generalised cost of travel directly through fares, parking or tolls, or indirectly by increasing the travel time on modes, for example bus prioritisation may increase travel times for car users. These changes in generalised costs may be a deliberate act of the policy (e.g. imposition of tolls), or an indirect consequence of it (the act of speeding up buses results in a slowing down of car traffic). Secondly, background traffic growth arising from income, demographic and land use changes may increase the level of congestion on the transport network.

The Rule of a Half accommodates suppressed demand. For a price rise initiated by transport policy the supply curves in

Figure A-1 and Figure A-2 are just reversed. Figure A-3 illustrates the situation for that of exogenous traffic growth over time. The key aspect here is that in an appraisal we focus on each point in time – in this case 2020 and 2025 – and the difference between the Do Minimum and the Do Something. Within this framework there is no need to consider the dynamics of how traffic grows, increasing the cost of making trips from C_0 to C_2 (in Figure A-3) and thereby suppressing some of the existing trips (Q_0) that had been undertaken at the previous lower price of C_0. The user benefit in 2020 is given by the Rule of Half (the sum of Areas A^{2020} and B^{2020}), and the user benefit in the later time period, 2025, is given by the Rule of Half applied in that time period (the sum of Areas A^{2025} and B^{2025}). It is of course essential that demand modelling framework is able to correctly model the changes in travel costs and demand in the Do Minimum and the Do Something. Failure to do so can result in significant errors in the appraisal – particularly if future years are congested in both the Do Minimum and the Do Something.

Figure A-3 Appraisal of induced traffic with exogenous traffic growth

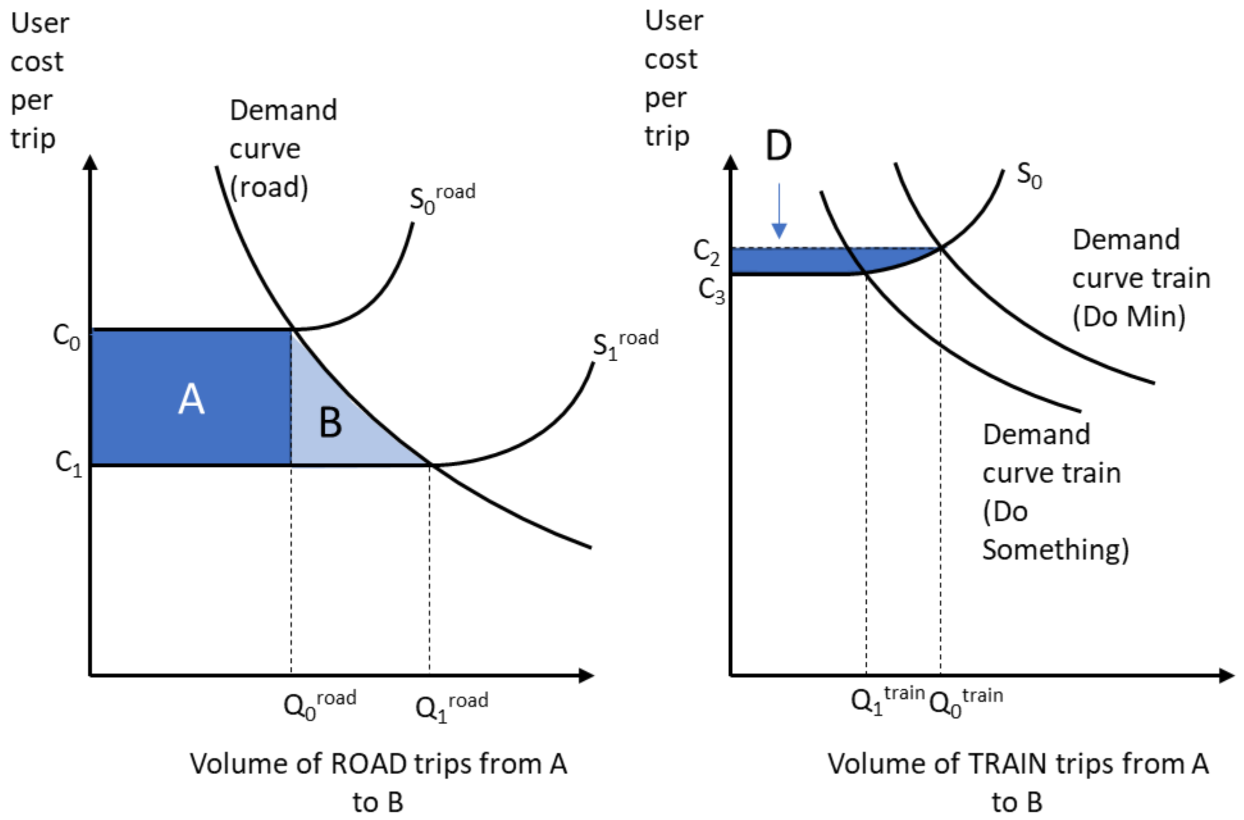


A.4 CAPTURING THE SOURCE OF THE INDUCED TRAFFIC IN THE APPRAISAL

What if the induced traffic (the difference between Q_0 and Q_1) arises as a result of travellers switching destinations, modes or time periods? In these situations Figure A-1, Figure A-2 and Figure A-3 tell only part of the story. It is important to consider what happens at other destinations, on other modes and in other time periods. In essence we have consumer surplus for each mode, time period and origin and destination pair and each one has to be considered in an appraisal. One can only ignore a mode, time period or origin destination pair in an appraisal if costs are not expected to change between the counterfactuals (the Do Minimum and the Do Something).

In the example depicted in Figure A-4 a substantial proportion of the induced traffic on the road network has switched from the rail network. This is depicted by the shift inwards of the demand curve for train in the right hand diagram of Figure A-4. The rail network service has remained the same – the supply curve for rail trips is unchanged. However, previously the rail network was heavily overcrowded – this can be seen in the rail portion of the diagram as the rail supply curve is upward sloping. The reduction in demand for the rail service reduces the level of overcrowding thereby giving a benefit to rail users who continue to use the service. This user benefit is shown by Area D. If these are all the impacts of the road investment on transport users, total user benefits would be given by the sum of Areas A, B and D.

Figure A-4 Multi-modal appraisal with an overcrowded train service



Taking the demand curve to be linear this can be approximated by calculating the Rule of Half for each mode and summing them together. In addition to this change in user benefits there will also be changes in producer surplus (the benefits accruing to the rail operator – who will lose revenue). If the rail operator receives a public subsidy to operate the train service, it is likely that the government may need to make up this shortfall. This will then have impacts for the government's transport budget in addition to the investment and maintenance cost of the improved road network. This all forms part of the appraisal.

If the train service was not overcrowded there would be no reduction in overcrowding on the train service and therefore Area D would be zero. Areas A and B (on the road network) would give the measure of the total user benefits from the road improvement. The reduction in demand for the train service would still have impacts on the rail operator and the government.

In this simple example we can therefore see the importance of looking beyond where the induced traffic occurs, and broadening the appraisal to include the sources of induced traffic. There are well established procedures, embodied in WebTAG (see DfT, 2017 Appendix A)[47], where these sources relate to modes, time periods and destinations. The formulas presented in WebTAG cover the range of impacts on users, the suppliers of transport services and government. External costs associated with the environment and safety related to the appraisal (including that associated with induced traffic) are also set out in the guidance. More problematic are the benefits associated with land use change. These benefits are closely related to economy impacts and therefore wider economic impacts. We discuss these in Section A.6. Before doing so we discuss the implications for appraisal of the extreme case in which so much traffic is induced that the congestion erodes all of the benefits. Duranton and Turner (2011)[48] called this the 'Fundamental Law of Congestion'.

[48] Duranton, G. and Turner, M.A., 2011. The fundamental law of road congestion: Evidence from US cities. The American Economic Review, 101(6), pp.2616-2652.

A.5 THE FUNDAMENTAL LAW OF CONGESTION AND THE MOGRIDGE CONJECTURE

Anecdotally there have been claims that induced traffic fills roads up, thereby negating the benefits of the investment. In the UK the M25 is often cited as an example. In 2011 Duranton and Turner published a now seminal paper giving evidence that for US cities investing in inter-state highway networks has not reduced congestion on the inter-state highway network within the cities. This special case of total filling-up of new road space is often taken to imply that there have been no benefits from investing in that road space. The user costs before and after the investment are the same: the argument therefore goes there is no benefit. A more in depth analysis is however required before one can conclude that there have been no benefits from the investment.

If user costs on the infrastructure that has been upgraded are the same in both counterfactuals (the Do Minimum and the Do Something) then there is an appearance that no user benefits have been delivered. However, for there to be absolutely no user benefits we have to look to the all sources of the induced traffic, and ensure that no benefits occur to transport users who remain in the markets from which the induced traffic was derived (e.g. there are no de-congestion benefits on the local road network). In relation to Figure A-4 this would mean that Area D would have to be zero as well Areas A and B. If decongestion benefits are felt in other parts of the system, then even if induced traffic negates benefits on the road that has been upgraded, the benefit of the investment will still be positive.

The situation for which there will be absolutely no benefits from transport investment as induced traffic has eroded it all away are quite specific (Dodgson (1991 cited in Mackie, 1996[45])):

- There are alternatives which are perfect substitutes for the improved facility;
- Some of these alternative facilities are not congested; and
- The improved facility will not attract all the traffic from these uncongested alternatives.

These are quite stringent conditions, and are unlikely to be met in road networks. Therefore even in the case of total filling up of the new road capacity by induced traffic, we would expect some user benefits. Turning back to the Duranton and Turner (2011) paper, we can see that their analysis focuses on the major road network in cities and does not cover all roads – some benefits may therefore be experienced on local roads if traffic is routed away from these. Additionally Duranton and Turner report that one of the sources of the induced traffic is migration to cities which have had inter-state highway network investment. There are two sources of benefit that might be associated with this migration. Firstly, the locations from which population migrates from will experience some decongestion benefits and secondly the changes in land use associated with migration would be expected to be a source of benefit. We discuss this further in the next section.

Mogridge's conjecture (Mogridge et al., 1987)[49] presents an even worse scenario than the zero benefit scenario depicted above. If induced traffic reduces demand for public transport (as in the right hand side of Figure A-4), then the reduction in fare revenue may lead to either a contraction in train services or fare increases (unless the government makes up the revenue shortfall). This would shift the public transport supply curve upwards displacing more trips onto the road network and therefore eroding user benefits further. For a particular set of circumstances Mogridge et al. showed that the final equilibrium position could be higher transport costs on both the road network and the public transport network than prior to the investment. That is the induced traffic from the road investment initiated a chain of events that led to everyone being worse off. As Mackie says this is a nightmarish scenario, but it does depend for its validity on a number of conditions:

> *First, public transport fares must indeed exceed marginal operator costs; in peak period urban conditions, this is questionable. Secondly, there must be no public transport user benefits when traffic is shed such as relief of overcrowding or increased chance of a seat. Thirdly the principal behavioural mechanism must be modal transfer rather than redistribution or generation. It is, therefore, an argument relating to radial movements in big cities, where public transport has a large market share, but where investing in enhanced road capacity has become something of a rarity.* Mackie (1996)

[49] Mogridge, M.J.H., Holden, D.J., Bird, J. and Terzis, G.C., 1987. The Downs/Thomson paradox and the transportation planning process. International Journal of Transport Economics/Rivista internazionale di economia dei trasporti, pp.283-311.

Whilst the scenario depicted by Mogridge and colleagues is unlikely to be directly relevant to the DfT RIS programmes, it does once again highlight the need to consider the sources of the induced traffic when undertaking an appraisal. This is because benefits and disbenefits may occur in the markets from which the induced traffic is drawn.

A.6 LAND USE CHANGE AND WIDER ECONOMY IMPACTS

One of the sources of induced traffic is economic growth, specifically economic growth stimulated by the transport investment, as opposed to background economic growth.[50] Ultimately this manifests itself as higher average real incomes, delivered through higher levels of productivity and an increase in labour supply (employment levels). Part of the economic growth process is a change in land use. The simplest changes may be an intensification of use of existing land or the development of green or brownfield sites adjacent to new transport schemes. These changes in land use lead to changes in trip volumes and trip-making patterns – i.e. the changes in land use induce traffic.

From an economic appraisal perspective if transport user benefits are correctly measured, as in Figure A-1 to Figure A-4, then these economic changes and land use changes only hold value if market failures exist (Jara-Díaz, 1986[51], Mohring, 1993[52]). In the absence of market failures the value of the land use change is captured by the consumer surpluses associated with the induced traffic (Area B in the previous figures). It is therefore of interest to understand what market failures may lead to additional value to those already captured in the user benefits.

Laird and Venables (2017)[53] present a typology of market failures relevant to transport appraisal. They categorise them into three broad types: proximity and productivity due to agglomeration; induced investment and land use change; and employment. The appraisal framework they present then focuses on the correct identification of user benefits plus analysis that examines for the presence of market failures and the assessment of additional surpluses in non-transport markets that can be attributed to these. These additional surpluses are termed wider economic benefits.

If one of the sources of the induced traffic is increased economic activity stimulated by the transport investment, then this will only impact on the appraisal if one of the following occur:

- There are changes in agglomeration, which then change productivity levels;
- The economic growth occurs in industries which operate in an imperfectly competitive market;
- There is an increase in the supply of labour (and wages are taxed);
- Employment is displaced from one location to another and structural unemployment exists in one or both of those locations; or
- Development of new business or housing premises stimulated by the transport investment[54]

The Department's WebTAG guidance on wider economic impacts (DfT, 2017b[55]) uses this framework and gives guidance on the appropriate parameters to use and the analytical formulas to be employed. In contrast to the other surpluses, changes in land use associated with new developments are captured using a method of land value uplift. As land value uplift may also pick up other wider economic impacts, wider economic impacts associated with productivity, employment, etc. cannot also be included alongside land value uplift figures.

[50] Background economic growth is subject to a parallel literature review and was discussed earlier, in an appraisal context, in Section 0.

[51] Jara-Díaz, S. R. (1986). On the relation between users' benefits and the economic effects of transportation activities. Journal of Regional Science, 26(2), 379-391.

[52] Mohring, H. (1993). Maximizing, measuring and not double counting benefits: a primer on closed- and e economy cost benefit analysis. Transportation Research, 27(6), 413-424.

[53] Laird, J.J. and Venables, A.J., 2017. Transport investment and economic performance: A framework for project appraisal. Transport Policy, 56, pp.1-11.

[54] Laird and Venables (2017) show that land use change in itself can generate an externality as it increases the variety of goods on offer in a particular area. A statement of the issue is given by Simmonds (2012): "if a transport change improves access to a town centre and causes an increase in demand for shopping and services there, this is likely to lead to an improvement in the retail offer of that centre, which will be an externality benefit to residents with easy access to that centre".

[55] DfT (2017b) TAG Unit A2.1 Wider Economic Impacts Appraisal. December 2017.

Laird and Venables (2017) identify capturing the value of land use change as one of the three key challenges to the inclusion of the wider economic impacts of transport projects in appraisal. This is particularly the case if the land use change is stimulated by both the transport investment and by investment in the urban fabric. They think that a multi-market analysis with changes in welfare measured at the household level is one solution to this problem – for instance using spatial computable general equilibrium (S-CGE) models (Bröcker and Mercenier, 2010)[56] or land use transport interaction (LUTI) models (Martinez and Araya, 2000[57]; Simmonds, 2012[58]). The modelling techniques needed remain relatively rare in the context of most transport appraisals, and the methods for the calculation of welfare benefits remain on the research frontier in the transport context – see also the discussion in the next section.

A.7 WHEN THE RULE OF HALF IS INADEQUATE

The Rule of Half uses a linear approximation of the demand curve to provide an estimate of user benefits. More formally it approximates the Marshallian consumer surplus. This approximation is generally good, but can lead to significant errors in certain situations, as described here.

Where cost changes are large (>33 per cent) Nellthorp and Hyman (2001)[59] find that the error associated with the Rule of Half becomes large (>10 per cent). The method of numerical integration - where the curvature of the demand curve is approximated through one or two intermediate points - is one method that can be used when the transport project gives rise to such large cost changes. Nellthorp and Hyman (2001) describe this method. Alternatively the change in consumer surplus can be estimated through the direct integration of the area under the demand curve. This can only be done when the demand model includes a fully specified demand curve (e.g. a multi-nomial logit model). For the situation where the demand curve is represented using a logit function the evaluation measure used is known as the logsum. De Jong et al. (2007)[60] review the literature on this and present some results for some Dutch high speed rail projects. They find errors associated with the rule of half up to 32 per cent.

The externality associated with land use change discussed in the preceding section can also introduce an error into the Rule of Half (Laird and Venables, 2017). However, by explicitly incorporating the change in attractiveness at origins and destination into the consumer surplus calculation this error can be eliminated. There are very few examples of this approach in the literature: Geurs et al. (2010)[61] give one for the Netherlands and Börjesson et al. (2015)[62] present one for Stockholm, Sweden. An alternative approach is that adopted by the DfT. In their wider impacts guidance[55] they use land value uplift estimates to measure benefits where development is dependent on the transport infrastructure. An important point to note in their method is that the land value uplift estimate also encapsulates the benefit associated with the induced traffic (Area B in Figure A-1 to Figure A-4). This Area B is therefore excluded from the analysis when land value uplift from dependent developments is included in the benefit measure.

A significant error in the user benefit estimation can also occur if real incomes change significantly. In this situation the correct measure of economic benefit is Hicksian compensating variation, and not the Marshallian consumer surplus (as measured by the Rule of Half). Again there is very little in the literature on this. The earliest work in a transport context was undertaken by Jara-Díaz and Videla (1990)[63] who found that for

[56] Bröcker, J. and Mercenier, J., 2011. General equilibrium models for transportation economics. A handbook of transport economics, pp.21-45.

[57] Martinez, F., Araya, C., 2000. Transport and land-use benefits under location externalities. Environ. Plan. A 32 (9), 1611–1624.

[58] Simmonds, D.C., 2012. Developing land-use/transport economic efficiency appraisal (www.davidsimmonds.com/files/LUTEE-paper-for-ETC-v3-111012-1.pdf)

[59] Nellthorp, J. and G. Hyman. 2001. Alternatives to the rule of a half in matrix based appraisal, Proceedings of the European Transport Conference, 10-12 September, Cambridge. London: AET Transport

[60] De Jong, G., Daly, A., Pieters, M. and Van der Hoorn, T., 2007. The logsum as an evaluation measure: review of the literature and new results. Transportation Research Part A: Policy and Practice, 41(9), pp.874-889.

[61] Geurs, K., Zondag, B., De Jong, G., De Bok, M., 2010. Accessibility appraisal of landuse/ transport policy strategies: more than just adding up travel-time savings. Transp. Res. Part D: Transp. Environ. 15 (7), 382–393.

[62] Börjesson, M., Jonsson, R.D., Berglund, S. and Almström, P., 2014. Land-use impacts in transport appraisal. Research in Transportation Economics, 47, pp.82-91.

[63] Jara-Diaz, S.R. and J.I. Videla. 1990. Welfare implications of the omission of income effect in mode choice models. Journal of Transport Economics and Policy. 24(1), pp. 83-93

medium income Chilean households the change in Marshallian consumer surplus is 12 per cent higher than the compensating variation. Daly et al. (2008)[64] using the Dutch national model system estimate that the compensating variation of a policy to introduce national road pricing with a very high per km charge is 34 per cent lower than the change in consumer surplus (i.e. the change in consumer surplus overestimates the 'exact' welfare benefit by just over 50 per cent). Laird (2009)[65] found a similar level of overestimation. It must be stressed that these errors are associated with large changes in real incomes. For Laird's study the increase in real household income stemming from the construction of a fixed link to a remote island was estimated to be 27 per cent. This is clearly a special case.

[64] Daly, A., G.C. De Jong, N. Ibanez, R.P. Batley and M. De Bok. 2008. Welfare measures from discrete choice models in the presence of income effect. Paper presented at the European Transport Conference, Noordwijkerhout, Netherlands, 6-8 October 2008. London: AET Transport.

[65] Laird, J.J. (2010) Transport welfare benefits in the presence of an income effect. In: HESS, S. and A. DALY (eds) Choice Modelling: the State-of-the-Art and the State-of-Practice, Chapter 18, pp.399-420. Bingley: Emerald.

Appendix B

SEARCH PROTOCOL

This appendix contains the search protocol used in the systematic literature search undertaken as part of the REA of the evidence on induced travel demand to inform the development of the Road Investment Strategy, which focuses on major road schemes in the UK.

B.1 SEARCH STRATEGIES

We used two strategies. The first included broad terms to capture as much relevant literature as possible. It includes three separate searches. These covered terms related to induced travel, terms related to generated traffic (often used as a synonym for induced travel but is also used in other contexts), and terms related to ex-post studies of road travel, which are also an expected source of empirical evidence.

SEARCH STRATEGY 1

- Induced travel OR induced traffic OR induced demand
- Generated traffic OR traffic generation
- Ex-post AND (road OR transport OR travel)

An additional search was subsequently run to ensure all induced demand terms were captured, as follows

- Induced vehicle travel OR induced vehicle demand OR induced motor vehicle travel OR induced motor vehicle demand[66]

A second search strategy was then employed to capture a thread of literature covering empirical work on the 'fundamental law of congestion', which does not always use the terminology of induced demand.

SEARCH STRATEGY 2

- (Vehicle miles travelled OR VMT OR vehicle-kilometres travelled OR VKT OR traffic volume) AND (Road investment or road capacity OR lane kilometres OR road network capacity)
- Latent demand and road

B.2 INCLUSION CRITERIA AND DATABASES

Inclusion criteria were developed to set the framework for the literature to be included in the review. Including literature reviews in the types of publications means that important literature published more than ten years ago would be captured. Contacts provide another source for this.

Three databases were used that cover transport, economic and wider scientific literature.

Criterion	Value
Published in or after year	2007
language	English only
Location of study	UK, Europe, OECD
Type of publication	Journal article, conference abstract/paper, PhD theses, high quality agency reports,
Study type	Quantitative empirical analyses, preferably with comparator, modelling studies
Scope	Road passenger transport, Road freight transport
Databases	
Academic (subscription) databases	TRID, Econlit ,Web of Science[67]

[66] This search was run in TRID and Web of Science only.

[67] The TRID database integrates the content of two major databases, the Organisation for Economic Co-operation and Development's (OECD's) Joint Transport Research Centre's International Transport Research Documentation (ITRD) Database and the US

B.3 PILOT TESTING OF SEARCH TERMS

The search terms were tested and revised accordingly to make sure they were broad enough to capture key papers known to the project team or identified by experts.

No.	Paper	Found in search
1	Duranton G. and M.A. Turner (2011) The Fundamental Law of Road Congestion: Evidence from US Cities, American Economic Review 101, 2616–2652.	Yes
2	Graham, D., McCoy, J. and D.A. Stephens (2015) Quantifying Causal Effects of Road Network Capacity Expansions on Traffic Volume and Density via a Mixed Model Propensity Score Estimator, Journal of the American Statistical Association.	Yes
3	Hymel, K.M., K. Small, K. Van Dender (2010) Induced demand and rebound effects in road transport, Transportation Research Part B.	Yes
4*	Litman T. (2017) Generated Traffic and Induced Travel: Implications for Transport Planning, Victoria Transport Policy Institute.	No
5	Noland, R. (2007) Transport Planning and Environmental Assessment: Implications of Induced Travel Effects, International Journal of Sustainable Transportation.	Yes
6	Rohr, C., Daly, A., Fox, J., Patruni, B., van Vuren, T. and G. Hyman (2012) Manchester Motorway Box: Post survey research of induced traffic effects– *The Planning Review*, ETH Zürich.	Yes
7	Sloman, L. L. Hopkinson and I. Taylor (2017) The Impact of Road Projects in England, CPRE. (Evidence from POPEs and Meta-analysis).	No, grey literature.
8	Graham, D. (2014) Causal Influence for Ex-Post Evaluation of Transport Interventions, Discussion Paper No. 2014-13	Yes
OTHER PAPERS IDENTIFIED BY EXPERTS		
9	Loop, J.T.A. van der, Waard, J. van der, Haaijer, R. and Willigers, J. (2016) Induced demand: new empirical findings and consequences for economic evaluation, Paper presented at TRB 2016.	Yes
10+	Nicolaisen, M.S. and Driscoll, P.A. (2016) An International Review of Ex-Post Project Evaluation Schemes in the Transport Sector, Journal of Environmental Assessment Policy and Management.	No, but pick up other papers by same authors

Transportation Research Board's (TRB's) Transportation Research Information Services (TRIS) Database. Econlit is the American Economic Association's database on worldwide economic literature, including peer-reviewed journal articles, working papers from leading universities, PhD dissertations, books and conference proceedings. Web of Science is a citation index, with 5294 publications in 55 disciplines as well as 160,000 conference proceedings.

No.	Paper	Found in search
11	Noland, R. & C. Hanson (2013) How Does Induced Travel Affect Sustainable Transportation Policy? Transport Beyond Oil: Policy Choices for a Multimodal Future, Editted by John L. Renne and Billy Fields, Island Press.	Yes
12	Weis, Claude, and Kay W. Axhausen. 2009. Induced travel demand: Evidence from a pseudo panel data based structural equations model. Research in transportation economics 25.1: 8-18	Yes

*This is a TRID error. It does include Victoria Policy Institute publications but had omitted this particular one.

B.4 RESULTS

The search strategies resulted in 1053 citations that were then screened by title, abstracts and keywords.

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