Department for Transport

TAG Unit M5.3

Supplementary Economic Modelling (SEM)

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Department for Transport

Transport Analysis Guidance (TAG)

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This TAG Unit is guidance for the Modelling Practitioner

This TAG Unit is part of the family M5 - Advanced Modelling Techniques

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1. Introduction

1.1.1 This TAG unit provides high-level guidance to inform the selection, specification, validation and reporting of Supplementary Economic Modelling (SEM). The unit sets out the most important principles of appropriate use of SEM, outlines established and emerging modelling approaches and presents key considerations of model specification, validation and assurance.

1.1.2 This guidance is mainly written for:

- technical project managers and modelling consultants who scope, develop, document or report SEM;
- peer reviewers of SEM; and
- Government analysts who wish to assess the weight that should be placed on SEM in a scheme's Business Case.

Non-technical policy stakeholders may also consult the first three sections of this guidance to learn about the circumstances when SEM may be appropriate (see section 2).

1.1.3 This TAG unit is structured as follows:

- Section 2 sets out the rationale of using SEM;
- Section 3 explains the basic requirements and assumptions in relation to SEM in transport appraisal;
- Section 4 summarises common and emerging types of SEM;
- Section 5 provides guidance to inform the selection of different types of SEM for appraisal;
- Section 6 describes in more detail technical considerations when specifying SEM;
- Section 7 provides guidance to inform model validation; and
- Section 8 specifies how SEM should be reported in the Business Case.

2. Rationale

2.1.1 SEM comprises methods to estimate the wider economic impacts (WEIs) of transport schemes. The methods are considered to be 'non-standard', because their robustness for use in appraisal has not been assessed, in contrast to the 'standard' methods covered in the TAG A1 and A2 units. Therefore, they should be used to supplement and not replace the standard transport appraisal methods set out in the TAG A1 and A2 units.

2.1.2 Alongside general guidance on the use of SEM in appraisal, this unit describes and compares in more detail selected basic supplementary economic models, specifically Additionality and Reduced-form models, and advanced models, specifically Land Use-Transport Interaction (LUTI) models, Spatial Computable General Equilibrium (SCGE) models, and Quantitative Spatial Economic (QSE) models. Other models not covered in this guidance may also be considered; the principles set out in this unit also applies to them.

2.1.3 SEM may be employed at different stages of the transport appraisal process,[1] for example:

- At an early stage to inform the strategic dimension of the Business Case, for example to identify viable alternatives and their place-based impacts as part of option development;
- At an advanced stage, to produce a full economic appraisal as part of the economic dimension.

Although this unit focuses on the use of SEM for full economic appraisal, the principles set out here should also be followed for strategic uses to ensure robustness and consistency with appraisal practice.

2.1.4 In contrast to standard transport appraisal methods, many types of SEM have not been externally peer-reviewed and systematically assessed for suitability and robustness in transport appraisal.

2.1.5 Advanced SEM approaches can be used to assess how transport schemes change the spatial distribution of economic activity and how these changes may in turn affect transport capacity, that is, how they induce so-called ‘transport external cost’. Therefore, these models are appropriate to study WEIs under conditions of land use change as defined in TAG Unit A2.1, where such impacts are also referred to as ‘level 3’ impacts.

2.1.6 SEM is most relevant in cases which are expected to

- cause significant land use change;
- generate benefits that depend on development; and
- interact with market failures in ways which cannot be assessed using standard TAG methods.

Furthermore, SEM may be used to test the sensitivity of modelling outputs using alternative sources of evidence to those described in TAG.

[1] For more details on the transport appraisal process, see Department for Transport (2018) at https://www.gov.uk/government/publications/webtag-transport-appraisal-process-may-2018
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2.1.7 SEM may help address several challenges in appraisal, in particular the accommodation of market distortions and the identification of both intended and unintended economic impacts in transport and non-transport markets. SEM may also be undertaken to:

- quantify user benefits that arise due to the spatial redistribution of economic activity;
- capture a broader range of WEIs than those recognised in the TAG A2 units, such as productivity gains from localisation effects, i.e. increased connectivity of single-industry clusters;
- obtain context-specific estimates of welfare impacts set out TAG Unit A2.1, such as mode-specific agglomeration elasticities;
- estimate economic impacts at high spatial granularity, such as changes in sub-national GDP, local employment or housing prices; or
- estimate costs and benefits under different future scenarios, for example the analytical scenarios described in TAG Unit M4.

2.1.8 SEM often produces estimates of non-welfare economic impacts, such as GDP or employment. The Department generally prefers estimates of a scheme's WEIs based on social welfare in accordance with the standard methods of transport appraisal. In principle, a scheme's GDP impact can be inferred from the welfare-based appraisal (see Appendix A for more details). Yet, these estimates may differ from the modelled impacts produced by SEM; and therefore, SEM may be considered when GDP impacts are expected to be significant.

2.1.9 SEM is usually not required to produce a robust Business Case, especially when transport schemes are small. If such modelling is not proportionate, expected impacts resulting from the scheme can still be presented in the Economic Narrative of the Business Case.

2.1.10 The decision to undertake SEM should be justified in the Economic Narrative (TAG Unit A2.1, section 5). The justification should state the purpose of the analysis and the choice of modelling approach. In addition, it should be explained how:

- the analysis enhances the understanding of the scheme's impacts over and above that gained from standard TAG methods; and
- the complexity, time and financial cost of developing and running the models is balanced against the potential effect of the analysis on the Value for Money assessment.

Judgements on proportionality may differ depending on whether an existing 'off-the-shelf' model can be adapted or a bespoke model needs to be developed.

3. Basic Requirements and Assumptions

3.1.1 SEM should be based on the economic principles and assumptions set out in the HMT Green Book[2] and TAG Units A1.1 and A2.1. TAG assumes that user benefits capture all economic impacts of the transport investment when the economy operates efficiently, that is, under conditions of full employment and perfect competition. Allowing for national economic impacts over and above those captured by user benefits must be justified through the presentation of context-specific evidence on market failures or distortions as defined in TAG Unit A2.1.

3.1.2 The default assumption in the labour, capital and product markets is that resources are fully used; that is, wages, return on capital and prices fully adjust to ensure that there is no unemployment, idle physical or financial capital or unsold output. Therefore, changes in the demand for labour, capital or products *per se* are assumed to not affect economic output and instead displace economic activity from other locations or industries.

3.1.3 Taking these default assumptions as a starting point, SEM may be used to successively relax some of the default assumptions and systematically analyse and document the effect on the appraisal. Where SEM is used to estimate impacts that are not covered in TAG, it is particularly important to document and examine the modifications to default assumptions.

3.1.4 The choices of whether to conduct SEM and which type to select should also be informed by considerations of cost and proportionality. Circumstances that affect model development costs include:

- whether a new model is specified or an 'off-the-shelf' model can be adapted;
- the number and complexity of modelling functions;
- the spatial and temporal resolution; and
- the required level of specialism and associated staff cost.

Further model-specific cost considerations are mentioned in the respective sub-sections of section 4. Section 5 provides guidance on which model type may be suitable for different types of schemes.

3.1.5 Given the high level of uncertainty associated with SEM, any monetised estimates from these models should only be reported as part of the indicative benefit cost ratio. The estimates must be based on the analytical principles and considerations set out in section 6 below. The Department's Value for Money guidance[3] defines how the estimates should be included in the Value for Money assessment.

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[2] The HMT Green Book is available at https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-government/the-green-book-2020

[3] The Value for Money Framework is available at https://www.gov.uk/government/publications/dft-value-for-money-framework.

3.1.6 Where SEM is used to estimate GDP impacts, welfare estimates must be obtained using the same assumptions. This is to ensure consistency between the evidence informing the Value for Money assessment and non-welfare metrics. Section 6.5 provides guidance on how SEM can be used to obtain social welfare estimates.

3.1.7 Where SEM is used to estimate sub-national economic impacts, for example for the purpose of place-based analysis (TAG Unit A4.3), equivalent national impacts must be estimated using the same assumptions. The purpose is to provide decision-makers with evidence about potential displacement effects.

3.1.8 SEM needs to be documented in order to enable decision-makers to assess the weight that should be placed on the model results in the scheme's Business Case. At a minimum, the report should describe how the models were

- specified according to each modelling aspect covered in section 6; and
- validated and quality assured as defined in section 7.

Section 8 lists all technical aspects of the model development that should be reported.

4. Overview of Supplementary Economic Models

4.1 Introduction

4.1.1 This section outlines the following common and emerging approaches to Supplementary Economic Modelling:

- Basic supplementary economic models ('basic SEMs'), specifically Additionality and Reduced-form models;
- Land Use-Transport Interaction (LUTI);
- Spatial Computable General Equilibrium (SCGE): and
- Quantitative Spatial Economic (QSE) models.

4.1.2 Due to functional similarities between some LUTI, SCGE and QSE models, the modelling field has generated hybrid or coupled variants. The use of such and other models not covered in this unit is permitted, too, and should be informed by guidance related to the best-matching model in this section.[4]

[4] See https://www.gov.uk/government/publications/supplementary-economic-modelling for detailed reviews of LUTI (Simmonds 2024), SCGE (Stroombergen & Laird 2023) and QSE (Graham & Hörcher 2024) and their application to transport appraisal, along with earlier reports on transport investment and economic performance by Venables et al (2014, https://www.gov.uk/government/publications/transport-investment-

4.1.3 There is currently no consensus in both practice and the modelling literature on the 'best practice' in using these models for appraisal. Therefore, models and scenario tests need to be tailored to the characteristics of the transport intervention while ensuring consistency with standard appraisal practice as much as possible, as set out in section 6.

4.1.4 Different types of SEM implement economic assumptions and thus identify the additionality of benefits in different ways. The economic phenomena affecting additionality relate to displacement and multipliers. The extent to which these phenomena can be captured depends on the spatial scale and the size of the geographical area considered in the appraisal. To ensure consistency with TAG, analysts should derive national impacts of the model estimates.

4.1.5 In this guidance, displacement can appear as:

- deadweight – the extent to which a public investment or policy 'crowds out' economic activity that would have occurred without the intervention, too;
- 'inward' displacement – the extent to which increases in economic outcomes, such as jobs or GDP, in the target area of an intervention cause reductions elsewhere; and
- leakage or 'outward displacement' – the extent to which impacts take place outside of the target area of an intervention.

4.1.6 Multipliers refer to the extent to which economic impacts are amplified by increased business and consumer spending, which are known as indirect and induced multiplier effects respectively.

4.2 Basic Supplementary Economic Models

Model overview

4.2.1 Basic supplementary economic models (in the following 'basic SEMs') refer to different approaches that estimate the impact of transport investments based on simple heuristics or statistical relationships. They typically focus on one type of market failure identified in TAG Unit 2.1 and do not consider impacts on the entire economy.

4.2.2 The Department recognises two types of basic SEMs:

- Additionality models, which estimate the impact of government interventions on net GDP or employment based on several explicit assumptions about the local economy; and

and-economic-performance-tiep-report) and appraisal methods for sub-national, regional and local economy impacts by McCartney et al (2013, https://www.gov.uk/government/publications/modelling-and-appraisal-of-the-sub-national-regional-and-local-economy-impacts-of-transport).

- Reduced-form models, which use econometric techniques to predict changes in economic outcomes based on statistical associations with a transport investment's travel time and cost savings.

4.2.3 Basic SEMs can be used to estimate additional economic benefits, such as changes in welfare, GDP or employment, that would not have occurred without the transport intervention in the target area. However, they do not explicitly represent dynamics related to displacement and multipliers and thus rely on exogenous data or assumptions about these processes.

Economic Principles

4.2.4 Basic SEMs focus on empirical relationships between changes in transport accessibility and selected categories of WEIs. They are often based on implicit economic assumptions rather than explicit and formal specifications of behaviour at the micro level of economic agents, such as firms or households.

Additionality models – functionality and data requirements

4.2.5 Additionality models typically rely on local evidence to assess how the transport investment will affect the economy. Data sources may include local economic statistics, such as unemployment rates or the industrial split of production, interviews with stakeholders about how they might respond to the transport improvement or local growth and development plans. Publications of more detailed Government guidance on additionality modelling can be found in Appendix B.

4.2.6 Additionality models are often used to value the increase in net GDP or employment associated with 'dependent developments', which are a special category of development that is made possible by local transport improvements make possible (see TAG Unit A2.2). Net GDP and employment impacts can be valued by first estimating the gross GDP or employment of those businesses that occupy these developments and, second, by assessing the extent to which these impacts are additional.

4.2.7 The standard approach to estimate the gross GDP and employment associated with dependent developments comprises the following steps:

1. Identify potential dependent developments;
2. Estimate the floor space covered by these developments;
3. Estimate the gross number of jobs located at these developments by making assumptions about occupancy rates, for example by using official statistics or estimates;
4. Estimate the gross GDP associated with the developments by multiplying the gross added jobs by the assumed GDP per person.

4.2.8 The net change in GDP and jobs can be estimated by adjusting the gross GDP and jobs estimates by displacement and multipliers. This should be done based on context-specific information for the scheme in question.

4.2.9 Estimates of displacement and multipliers should be based on existing guidance or relevant evaluation evidence from other comparable settings. Appropriate sources include:

- TAG Unit A2.2, which provides guidance for assessing the level of deadweight and inward displacement associated with dependent developments;
- estimates by the Department for Business Innovation and Skills (2009) covering all aspects of displacement and multipliers at regional and local levels; or
- other evidence from Government evaluations, listed in Appendix B.

Given that inward displacement (see paragraph 4.1.5) is expected to be greater at the national than regional or local levels, inward displacement estimates from the Department for Business Innovation and Skills (2009) may be used as lower bounds for the national impact.

4.2.10 Additionality models typically assume that transport schemes only raise net GDP or employment in the short run and that these impacts become deadweight in the long run. Evidence from previous impact evaluations on regional development (Office of the Deputy Prime Minister 2004) suggests that net GDP and jobs benefits should be assumed to persist for 10 years; however, the Department for Communities and Local Government (2010) have previously adopted a more cautious assumption of 5 years.

Reduced-form models – functionality and data requirements

4.2.11 Reduced-form models have been used to estimate the relationship between changes in effective densities afforded by the transport scheme and economic impacts. Effective density, also called Access to Economic Mass (ATEM), is defined as a metric for the number of households or businesses that can be accessed from a given location. The metric incorporates a decay parameter, which reduces the weight of more distant activities (for the standard equation, see TAG Unit A2.4).

4.2.12 Reduced-form models can be used to estimate the impact of a proposed transport scheme on economic activity and outcomes. To do so, the models require elasticity values of economic activity with respect to effective density, which may be obtained from existing empirical studies or original research. When elasticity values are available, the economic impact can be estimated in two steps:

1. Estimate the change in effective density for locations affected by the transport scheme;
2. Calculate the economic output measure of interest applying the elasticity to the change in effective density.

4.2.13 Reduced-form modelling is commonly applied to estimate agglomeration benefits that arise from transport investments. The standard approach for estimating agglomeration benefits is to follow guidance in TAG Unit A2.4 based on the national agglomeration elasticities published in Graham et al. (2009). In some circumstances, reduced-form models may be used to estimate agglomeration benefits using alternative elasticities. Alternative parameter values may also be used to conduct sensitivity tests.

4.2.14 Context-specific agglomeration elasticities may be used if the national-average elasticities from Graham et al. (2009) are judged to be unrealistic or if different functional forms seem more appropriate. For example, since the elasticities quoted in TAG Unit A2.4 assume a linear relationship between effective density levels and agglomeration benefits, the default elasticities may under- or over-estimate agglomeration benefits for the very largest cities and adjustments may produce more realistic estimates.

4.2.15 Reduced-form models may be calibrated on local data to appraise specific outcomes of interest, for example localisation effects (see TAG Unit A2.4), which are particularly relevant for inter-city transport schemes. Similarly, modellers may consider calibrating the models on local data when urbanisation effects of intra-city schemes seem particularly relevant.

4.2.16 Bespoke reduced-form models require sufficiently detailed local data, which may be obtained from publicly available national and local statistics on the location of households, the location of businesses and local labour market characteristics, such as wages or employment rates. It is important to consider the geographic scope of these models in order to identify potential displacement. Additionality models may be used to adjust estimate impacts by displacement and multiplier effects.

Use in appraisal

4.2.17 Basic SEMs are appropriate when more context-sensitive estimates of WEIs are needed and when WEIs are likely to be of lower importance relative to transport user benefits in the Value for Money assessment. Since the models are simpler than other types of SEM, they are often more suitable for schemes of local or regional extent.

4.2.18 Because the models focus on empirical relationships and are thus agnostic to economic theory, they are not suitable to explicitly model economic activities under different market conditions, such as imperfect competition. Instead, the models offer simple heuristics to estimate economic impacts for which explicit representations of economic processes are not required, notably impacts related to dependent development, productivity and GDP.

4.2.19 Despite their simplicity, basic SEMs need to undergo sensitivity testing. When using Additionality models, analysts should test the effect of different plausible assumptions for deadweight, displacement, leakage and multiplier effects. Reduced-form models should be examined regarding their sensitivity to different elasticities. The impact of other statistical parameters and choices that influence results, such as functional forms or different choices of control variables where used, should also be tested.

4.3 Land Use-Transport Interaction (LUTI) Models

Model overview

4.3.1 Land Use-Transport Interaction (LUTI) models comprise a diverse set of approaches that simulate the impact of changes in transport cost on land-use. LUTI models assess a) the impact of transport – the 'primary' market – on closely related 'secondary' markets, such as jobs, housing or real estate; and b) feedback from the changes in secondary markets on transport capacity, so-called 'transport external costs'. In the context of LUTI models, the term 'land use' primarily refers to the spatial distribution of residential households and employment.

4.3.2 The basic unit of analysis is the spatial zone. The zonal design may be adopted from an existing system, for example census zones, or developed bespoke, akin to traffic analysis zones. The flexible zonal design and the high spatial resolution is one of the strengths of LUTI models – data availability permitting.

4.3.3 Many models consider the supply and price of residential or commercial floorspace. In these models, the supply of floorspace in each zone can be either exogenously defined or forecast by the model subject to constraints. Some recently developed LUTI models also incorporate inter-industry linkage based on input-output data and thus incorporate some functionality of general equilibrium models (section 4.4).

4.3.4 In the context of appraisal, LUTI models can be used to understand how a transport investment will affect the spatial distribution of residential households, employment, firms or related activities. They thus provide a foundation to assess a wide range of place-based effects, including agglomeration due to *dynamic clustering* (TAG Unit A2.4) and displacement; the latter by highlighting where increased zonal activity might be offset. Fully specified LUTI models also simulate the two-way interaction between the spatial redistribution of activity and the transport system.

Economic principles

4.3.5 LUTI models are based on the idea of utility expressed at the level of zones. The simplest representation of utility is through gravity or spatial interaction equations, which estimate the spatial distribution of an activity based on the spatial distribution of another. For example, the distribution of households may be estimated given the distribution of jobs and the characteristics of the transport network. More complex models adopt a micro-economic framework, wherein the relocation of households or firms are modelled as utility or production functions.

4.3.6 Transport investments can increase the attractiveness of zones and thus induce relocations of economic activity, which in turn can affect travel flows between locations. Simple LUTI models may find a new equilibrium by fixing one activity – that is, either households or employment – and allowing another to adjust.

When the zonal counts of more than one activity may vary, the model needs to specify the sequence in which activities adjust.

4.3.7 More sophisticated models simulate sub-groups of activities, for example types of households or types of employment or businesses. Utility, production or related functions can be used to estimate each sub-group's probability to relocate. Further model components can be added to represent household formation and dissolution processes, tenure choice, real estate development, planning constraints and inter-industry input-output linkages. Each component may define specific equilibrium or 'market clearing' conditions.

4.3.8 Market clearing behaviour is further affected by the ways in which LUTI models treat time. In static models, which do not consider time, all modelled markets clear simultaneously. In models that simulate adjustments at discrete time steps, markets clear sequentially. Dynamic equilibrium models may possess 'transition' sub-models that reconcile micro-level dynamics with externally provided demographic or economic forecasts.

Model types, functionality and data requirements

4.3.9 According to Simmonds (2024), existing LUTI models can be typified along two axes – the degree to which they incorporate a) time and b) monetary prices in their modelling.

- Time: static models forecast a new equilibrium situation following a transport intervention or change in transport cost; whereas dynamic models simulate gradual changes over time, which may be based on systems dynamics or microsimulation functionality.
- Prices: the simplest models simulate relocation of activities without considering prices explicitly; whereas models with monetary terms consider quantities and prices across several markets using utility or production functions, thus resembling general equilibrium models (sections 4.4 and 4.5).

4.3.10 Static models require exogenous input defining interzonal transport cost and zonal allocation of activities, specifically households and employment. Transport cost can be represented in monetary or non-monetary terms, e.g. travel time. Upon modification of the cost matrix, the models produce instant forecasts of the spatial distribution of activities.

4.3.11 Dynamic models work in time steps, e.g. years, and require demographic and economic scenarios for each year, which may be exogenously provided or endogenously estimated based on defined transition parameters. Systems dynamics models forecast change without converging to equilibrium solutions at each time step. By contrast, models using microsimulation often provide iterative adjustments at each time step to make some or all markets clear. Many dynamic LUTI models are calibrated by reference to parameters published in the urban and regional economics and related literatures.

4.3.12 Non-monetary models do not possess explicit market-clearing mechanisms. In models with monetary terms, prices across several markets adjust – and data requirements are more extensive. Zonal supply and rents of residential and commercial floorspace affect location decisions of households and businesses as well as the quantity that is consumed of each.

4.3.13 Models that consider changes in consumption due to changes in disposable incomes may be calibrated on exogenous data on inter-industry linkages and final demand. Such models require simplified, spatially disaggregated monetary flows between industries and households akin to Social Accounting Matrices (see paragraph 4.4.12), possibly with household sub-groups defined according to, for instance, skill levels.

4.3.14 LUTI model forecasts may be further adjusted by exogenously provided demographic or economic projects and planning constraints. In more monetised models, it is common that prices adjust while global supplies of labour and floorspace are fixed.

Use in appraisal

4.3.15 LUTI models may support appraisal, if transport investment are expected to cause a) significant shifts in the spatial redistribution of activities or the supply or prices of floorspace or land; or b) advance specific spatial strategies, such as regeneration. LUTI models are particularly suited for appraisal where these impacts need to be understood at a high level of spatial resolution, for example, neighbourhoods or other intra-city zones, along with associated feedback effects on transport capacity.

4.3.16 LUTI models can forecast changes in location of activities; therefore, they can provide a basis for the impact of benefits that occur under land-use change (‘level 3’ benefits). They are particularly suitable for assessing:

- agglomeration impacts arising from a) *dynamic clustering* of economic activity, making possible a fuller estimation of productivity gains, and b) household’s *move to more or less productive jobs* based on a utility-based choice framework;
- the impact of land market failures, specifically land rationing, imperfect competition and co-ordination failure, if developers, planning authorities and planning constraints are represented; and
- the location, scale and likelihood of dependent development.

Furthermore, LUTI models may be used to explore how exogeneous demographic trends, such as population growth or shrinkage, may affect the spatial distribution of transport WEIs.

4.3.17 LUTI models are less suitable for the estimation of non-welfare impacts, such as changes in GDP, because they usually focus on a narrower range of markets that are closely related to the transport market. Nevertheless, LUTI models may provide spatial input into general equilibrium models that consider the role of tax, government, savings and investment (section 4.4).

4.3.18 The extent and focus of sensitivity testing should be adapted to and proportionate with the complexity of the model, in line with the typology presented in paragraph 4.3.9. Special consideration should be given to the uncertainty about relocation decisions of households and firms, the impact of land and planning constraints and – where applicable – demand elasticities for land or floorspace.

4.3.19 The specification and cost of LUTI models should be proportionate to the scale of a) the investment to be appraised and b) the expected wider economic benefits arising specifically from the spatial redistribution of activities. The model should also be specified appropriately considering the availability and robustness of input data. Cost will also vary with the required level of spatial disaggregation.

4.4 Spatial Computable General Equilibrium (SCGE) models

Model overview

4.4.1 Computable General Equilibrium (CGE) models are large-scale numerical models that simulate interactions between industries, households, government, investment and – in open economy models – at least one external global region for international trade. CGE models forecast changes in supply, demand and income observed on product and factor markets. This functionality can be extended to multiple economies (often countries) in Multi-region CGE models or to sub-national regions or zones in Spatial CGE (SCGE) models. The models are referred to as ‘general equilibrium’ models because they represent economic interactions across the economy.

4.4.2 The unit of analysis in CGE models are accounts, i.e. industries, commodities, factors of production (wages, capital and land), households, government, investment and global trade. In national SCGE models, these accounts are nested in multiple sub-national regions. Some SCGE have also been developed for city regions. SCGE models typically have a lower spatial resolution than LUTI models due to the need to disaggregate data that are usually collected at national level.

4.4.3 Most SCGE models cover an entire national economy or a large region within a country. The main interest in using SCGE models lies on the national and regional macroeconomic impacts of changes on product and factor markets, which in turn result from a new policy, an investment or another external ‘shock’. SCGE models vary in the number of industrial sectors they represent and whether they include land markets. SCGE models calibrate and estimate the monetary flows between all regions and all accounts, that is, the quantities and prices of consumed commodities and factors of production.

4.4.4 SCGE models are best suited to assess the aggregate economic impact of large-scale transport investment under market distortions, such as imperfect competition and taxation. Specifically, the models can assess:

- how changes in transport cost may influence prices, wages and the supply and demand of products and factors of production on different markets and in different regions;
- how the transport investment affects the fiscal situation of government – both by modelling how the transport investment is funded and how tax revenues may change during the operation of the transport scheme;
- the scale of any WEIs that may ensue, such as productivity, labour supply, tax revenue and GDP growth; or
- crowding out effects on private investment, deadweight loss and other phenomena affecting the allocative efficiency of the economy, which – in SCGE models – may include regional shifts in economic activities.

Economic principles

4.4.5 CGE (including SCGE) models are based on behavioural functions derived from microeconomic theory. The main functions are production functions for profit-maximising industrial sectors (or representative firms) and utility functions applied to utility-maximising households. These functions determine what quantities of factors of production and commodities firms use to produce and what commodities households consume based on the income they gain from participation in factor markets.

4.4.6 How markets clear depends on the macroeconomic closure rules defined in the CGE models. In most cases, prices and wages are assumed to adjust such that supply and demand in all markets remain in equilibrium. Allowing prices and wages to be determined endogenously implies that, based on the behavioural functions for each account, the models produce the most efficient allocation of monetary resources under fixed supply of factors and commodities. For example, a price reduction of a commodity due to lower transport cost may be expressed in lower purchaser prices and thus becomes manifest in a different commodity mix consumed by industries, households or government. Alternatively, some prices, such as wages, may be fixed while the supply of labour adjusts endogenously.

4.4.7 CGE models allow easy and flexible changes of market clearing rules and it is good practice to test the impact of a policy or shock under different market clearing settings. In SCGE models, it is possible to define different market clearing assumptions for different scales. For example, labour supply can be fixed nationally but allowed to vary regionally to allow for local employment effects (see TAG A2.3) or geographical labour migration.

4.4.8 Other important areas of macroeconomic closure relate to the external balance of payments, investment and the government’s fiscal balance. The setting of these rules will depend on the nature of the transport investment, the degree to which the investment interacts with international trade, the source of investment and other contextual economic characteristics that are deemed relevant.

Model types, functionality and data requirements

4.4.9 Models can be classified according to how they treat time.

- In static SCGE models, a new equilibrium will be presented as a snapshot for a particular forecast year and the outcomes of interest may then be interpolated between the forecast year(s) and the base year.
- Dynamic models consider the time it takes for different accounts to adjust based on different assumptions about the foresight of agents that are represented by the accounts. Perfect foresight is the characteristic of intertemporal equilibrium (IE) models, in which expected prices drive all the decisions by economic agents, who tend to bring investment forward. By contrast, in sequential equilibrium (SE) models, there is no foresight and hence there is only iterative and no anticipatory adjustment.

4.4.10 The most important parameters relate to the behavioural functions, notably the industry production functions and the household utility functions. Common specifications of these functions are based on substitution elasticities (McFadden 1963; Powell & Gruen 1968), such as Constant Elasticities of Substitution (CES), Constant Elasticities of Transformation (CET) or the specifications according to Cobb and Douglas (1928). Function parameters or their underlying elasticities are often derived from independent econometric studies. Other parameters relate to labour supply and external trade.

4.4.11 In transport-focussed SCGE models, a range of additional elasticities pertaining to transport and location choices may need to be defined. For example, many models define elasticities governing fuel substitution, the choice of transport mode by businesses and households and spatial location decisions. Household elasticities for the substitution of commodity consumption, labour and leisure may also be needed.

4.4.12 Core data for a CGE model comprise national Social Accounting Matrices (SAMs). These matrices provide the monetary flows between all accounts, i.e. industries, factors of production, households, government, investment and international trade. Each of these broad accounts are typically broken down by different industrial sectors and commodities, types of factors, types of households, different types of government tax revenues and subsidies. SCGE models require that these flows be disaggregated to regions based on ancillary demographic and economic data.

4.4.13 Specific data requirements for transport-focussed SCGEs will vary according to the context and objective of the proposed model. In most cases, analysts should include at least one transport-supplying industry, in particularly in models that focus on freight or business travel. Data on business travel for relevant service sectors may be needed. If the model focusses on households, household travel demand must be represented, which may be split into commuting and other purposes. Most models will require a specification of values of time as well as migration data between regions and into or out of the study area.

4.4.14 The higher the spatial granularity of the SCGE model, the more complex the required operations to disaggregate data. Apart from proportionality, modellers should consider the trade-off between spatial granularity and the risk of bias. Ancillary data to perform spatial disaggregation include zonal census counts of households and employment or output per industry, such as Gross Value Added. It is essential to explain the assumptions that underpin the disaggregation of trade flows between account entities.

Use in appraisal

4.4.15 SCGE models may be most suitable when national and regional impacts of transport investments are expected to be significant, whereas more local, place-based impacts are less important in the appraisal. Impacts of local extent cannot be easily represented in the coarser zones SCGEs typically use. In addition, the models are superior when testing fiscal impacts of transport investments, for example whether public investment need to be funded through additional revenue or reducing expenditure elsewhere. Similarly, SCGE models can be used to assess the specific impact of different fiscal interventions, such as subsidies or pricing policies, on other economic activities.

4.4.16 SCGE models can represent imperfect competition and can assess WEIs under such conditions. Tax revenue changes due to changes in labour supply or the relocation of economic activity between regions can be captured. Agglomeration and productivity impacts can also be estimated either endogenously or by special sub models. Land value uplifts can be captured if SCGEs are sufficiently granular, although the latter will increase the risk of inaccuracies due to the need for far-reaching data disaggregation.

4.4.17 SCGE models focus on market impacts and, if they are to be used in transport appraisal, may require adjustments to remove non-welfare GDP impacts. Certain welfare impacts, notably those related to non-work time savings, safety and the environment cannot be readily appraised in SCGE models. In principle, it is possible to include such benefits in utility functions, if they can be monetised. Special care is necessary to avoid double-counting of benefits captured in the appraisal of transport user benefits. The risk of double-counting may vary by the type of scenario (or ‘shock’) applied to the model.

4.4.18 Sensitivity testing is a critical activity, because validation is particularly difficult in SCGE models. Different validation strategies may be adopted, notably historical model simulations coupled with the attribution of impact components to different causes, for example the investment versus contextual economic or demographic changes. Nevertheless, data requirements can be significant and may render validation of all outcomes infeasible.

4.4.19 SCGE models can be costly to develop. Important cost-relevant considerations include the number of accounts and sub-accounts, e.g. industrial sectors, commodities, taxes, household types, the spatial granularity and the treatment of time. Access to existing software packages often require paid licences. Expertise in general equilibrium theory and its mathematical application is required to design scenarios and interpret results. The model input data will also need to be updated regularly by skilled personnel. Analysts may consider searching for and adapting suitable existing models to reduce costs.

4.5 Quantitative Spatial Economic (QSE) models

Model overview

4.5.1 Quantitative Spatial Economic (QSE) models, also called Quantitative Spatial Models (QSM), can assess the welfare effects of transport investments when the latter cause economic activities to redistribute geographically. Like SCGE models, QSE models are built on microeconomic principles and general equilibrium conditions. But, unlike SCGE models, they place a strong emphasis on estimating core model parameters, such as elasticities in utility and production functions, empirically from spatially granular input data.

4.5.2 The unit of analysis in QSE models are locations or spatial zones. Each spatial zone has certain economic, social and geographical attributes that determine how attractive they are for households to reside and work in and how productive businesses are. Households choose the pair of workplace and residential locations that affords the highest level of utility. In current QSE models, businesses location choices are not explicitly modelled. Local or national government may also be represented in the models, but the current QSE literature has hitherto rarely considered government.

4.5.3 Most transport-focussed QSE models represent housing markets, markets of goods and services and factor markets. The models may differ by the extent to which they represent different goods and services. The simplest models represent the market through an abstract, representative consumer good. Households and businesses trade quantities on each market for certain prices. These basic components ensure that QSE models represent partial equilibria on separate markets alongside general equilibrium aspects of the economy.

4.5.4 The field of QSE models is less mature than that of CGE and LUTI, and applications to transport economics are just emerging. At the time of writing, there are only very few QSE applications in which transport is adequately represented. As the field is rapidly evolving, researchers in transport economics identify significant potential of QSE models to inform the assessment of WEIs under conditions of land use change. Promising applications include:

- investigating detailed land use change and the spatial redistribution of economic activities at high spatial resolution;
- assessing various economic and welfare outcomes across markets and agents by harnessing the full detail of rich local databases.

Economic principles

4.5.5 QSE models are based on microeconomic theory and thus operate within the same conceptual framework as SCGE models do. Households are utility maximisers and businesses are profit maximisers. The behaviour of each representative agent is governed by utility functions and production functions respectively.

4.5.6 Households seek to attain maximum utility through optimal location decisions and businesses seek maximum profit through optimal composition of production factor inputs. In the simplest models, households choose a pair of residential and workplace locations that satisfies their preferences of housing and goods consumption while accessing the highest wages and minimising commuting cost. Producing businesses then adjust their use of labour, commercial floorspace and intermediate inputs (where specified).

4.5.7 In general, markets clear through equilibrating prices or quantities. On the transport market, exogenous travel costs determine the level of utility or profit that households or businesses derive from settling at a particular location. Thus, transport costs affect the purchase of goods, land and labour. In most current QSE models, transport costs are simplistically represented as a proportional reduction of delivered quantities of products and production factors, which is also known as the 'iceberg' representation of transport. Standard approaches based on value of time have rarely been implemented and would require careful consideration, if QSE models are to be used in appraisal.

4.5.8 QSE models assume that each location has a unique productivity and a unique amenity value that determine its attractiveness. These amenity values cannot be measured directly; instead, they are reflected in residuals when calibrating the economic functions based on local data, such as wages, housing prices and transport costs. These structural residuals are assumed to reflect local amenity (geographical advantage or disadvantage) insofar as the baseline situation is in equilibrium. Structural residuals thus act as idiosyncratic constants associated with each location in the choice set.[5]

Model types, functionality and data requirements

4.5.9 Like LUTI and SCGE models, QSE models may be specified as static or dynamic models. Most extant QSE models compare the equilibrium states before and after a policy intervention. By contrast, dynamic spatial equilibrium models represent the transition between two equilibrium states. This specification allows for the consideration of time lags in, for instance, relocation decisions and different levels of foresight among economic agents.

4.5.10 Structural parameters comprise elasticities that govern the relationship between transport costs and different benefits, behavioural parameters and parameters linked to functional forms. In QSE models, most of these parameters are estimated econometrically from baseline data; whereas a smaller number of parameters may need to be exogenously provided based on conventions or imported from other empirical settings.

[5] These constants are broadly comparable with zonal constants in LUTI models, which embody all unmeasured characteristics and treat them as unchangeable. This modelling feature may cause issues akin to omitted variable bias (see paragraph 6.4.4).

4.5.11 The most important structural parameters in transport-focused QSE models include commuting cost semi-elasticities, agglomeration elasticities, distance decay parameters, expenditure shares as defined in Cobb and Douglas (1928), elasticities of substitutions (MacFadden 1963) in production functions, where used, and Fréchet shape parameters determining the dispersion of the random part of household utility in the location choice problem. Fréchet distributions are probability density distributions that align with the multiplicative structure of the utility and production functions in QSE models.

4.5.12 At the minimum, transport-focused QSE models require baseline data on travel patterns (flows between origins and destinations), transport links and their capacity, wages by residence or workplace, commercial and residential floorspace and rents at each location. The main sources for these data are public local statistics, such as Census data, or on-request data from local transport and planning agencies.

4.5.13 More detailed QSE models may be specified to represent heterogeneity on different markets and sectors. Households may be differentiated by occupation and skill level and business by industrial sector. The latter would require data on inter-industry linkages to assess impacts of price changes of intermediate inputs due to the transport investment. Such linkages may only be relevant for large-scale interventions. To date, there is limited experience with transport-focussed QSE models that include such linkages or different household types.

4.5.14 The spatial resolution of QSE models depends on the spatial scale of the transport investment and data availability. There are no known technical limits to the spatial resolution. Modellers should be mindful of the trade-off between accuracy of estimates and spatial resolution. Any data disaggregation must be fully documented.

Use in appraisal

4.5.15 QSE models can be developed and adapted to appraise a range of transport investments, including local, regional or inter-city schemes of passenger or freight transport. By default, the models estimate level 1, 2 and 3 welfare impacts (TAG A2-1, section 3.2) in an integrated fashion. The disaggregation of benefits into impact categories is not currently possible. In order to approximate the welfare differences between the three levels of benefits, modellers will need to fix certain behaviours, such as production factor demand and location choices, and gradually allow them to adjust to a new equilibrium. Other approaches to estimate impact categories may be developed in the absence of an agreed standard practice.

4.5.16 QSE models can assess many benefits that arise due to market failures, in particular productivity impacts due to agglomeration, for example through a productivity term that depends on Access to Economic Mass (TAG A2.4), moves to more productive jobs and imperfect competition in product markets. In principle, tax distortions can be represented, too, but the relevant QSE literature still needs to evolve. The representation of other types of market failures on labour and land markets is less established to date. Most current QSE models take transport capacity as exogenous input and may be used to compare scenarios. There is less experience with QSE models that allow transport capacity to adjust endogenously, especially in the context of freight schemes.

4.5.17 The flexible nature of QSE models allows for transparent and extensive specification of welfare – data permitting. Utility functions are extendable to include any measurable welfare-generating aspect. Successive runs of models with different specifications may be necessary to identify specific welfare or economic output (GDP) effects.

4.5.18 In view of the nascent state of transport-focused QSE applications, the Department recommends extensive sensitivity testing and uncertainty analysis of model results. The limited number of structural parameters in QSE models facilitates ways to assess uncertainty based on parameter standard errors and confidence intervals, for example by using methods of randomised numerical simulations.

4.5.19 Compared with LUTI and SCGE models, QSE models may incur lower software costs because they are often implemented in non-proprietary Open-Source software. The source of code of existing models are often published and freely available. Nevertheless, expertise in spatial economics, transport economics and software coding will be required to understand and adapt these models appropriately to the appraisal case. Special care needs to be taken to specify models that adequately represent the geographical and economic context of the investment to be appraised. Given the lack of standards and best practice in the QSE literature, it is essential that appraisers provide detailed and transparent documentation of the models and their assumptions.

5. Model Selection

5.1.1 There is no modelling approach that captures all economic impacts of transport investments. Different approaches may be applicable to different contexts when considering the scheme's size and scale, its anticipated impacts and proportionality. For example, when appraising the benefits of an airport expansion, it may be appropriate to assess the impacts on UK trade, foreign direct investment and net migration – and therefore, developing an SCGE may be most appropriate. Such considerations should be explained in the Economic Narrative.

5.1.2 The extant SEM approaches have different attributes that may inform the choice of model. Table 1 presents a list of the most important attributes and selection criteria that may be considered including their respective main strengths, weaknesses and appropriate uses. More detailed descriptions of each aspect can be found in the preceding section 4.

Table 1 – Comparison of common and emerging types of SEM

	Basic – Additionality	Basic – Reduced-form	Advanced – LUTI	Advanced – SCGE	Advanced – QSE
Model attributes					
Economic foundations	none	none	implicit rationality	macro and micro-economics	micro-economics
Functional framework	adjustment	formula	diverse, often spatial inter-action / gravity	profit and utility maximisation	profit and utility maximisation
Unit of analysis	single region	spatial zones	spatial zones	accounts by region	spatial zones
Exogenous parameter input	medium	low	varies, often low	high	medium
Spatial resolution	none	medium	fine	coarse	fine
Selection criteria					
Scheme significance	local	regional	local or regional	national	local or regional
Magnitude of WEIs[1]	low but significant	medium	medium	high	high
Main types of WEIs	dependent development	agglomeration benefits from static clustering	agglomeration benefits from dynamic clustering	labour market and fiscal impacts; regional disparities	agglomeration benefits from dynamic clustering
Suitability for place-based analysis[2]	low	low	high	medium	high
Suitability to account for displacement	medium	low	high	high	high
Suitability to account for multipliers	medium	low	low	high	high
Experience with transport external cost	none	none	high	low	low but increasing
Experience with freight schemes	medium	low	low	high	low

	Basic – Additionality	Basic – Reduced-form	Advanced – LUTI	Advanced – SCGE	Advanced – QSE
Summary of strengths and weaknesses					
Main strengths	simplicity; context-specificity	simplicity; use of quantitative evidence	flexibility; high spatial resolution; data sparsity	consistency with national accounts; fine industry resolution inclusion of government, scheme financing and fiscal outcomes	flexibility; high spatial resolution; parameter estimation
Main weaknesses	non-generalisability; degree of subjectivity	context uncertainty	lack of overarching economic framework	complex data requirements; irregular data availability	simplistic representation of transport; low maturity of the field

Notes:
1 Wider Economic Impacts, see TAG Unit A2.1 (https://www.gov.uk/government/publications/tag-unit-a2-1-wider-economic-impacts).
2 see TAG Unit A4.3 (https://www.gov.uk/government/publications/tag-unit-a4-3-place-based-analysis).

5.1.3 The **functional modelling framework** range from simple heuristics in the case of Additionality models to complex behavioural optimisation embodied in general equilibrium models, which result from the models' specific economic foundations. The more explicitly the models represent economic behaviour, the more the models are capable of also identifying unintended consequences, for example, the geographical extent and pattern of agglomeration and disagglomeration due to displacement.

5.1.4 Some model attributes are closely related to data requirements and availability, specifically the **unit of analysis**, required exogenous parameter input and spatial resolution. The more exogenous parameters are needed, the more empirical data would need to be collected. The level of spatial resolution is positively associated with higher exogenous input, too.

5.1.5 Because reduced-form models employ pre-specified elasticities and LUTI models often assume gravity relationships, simple variants of these models can be specified on a relatively narrow range of **data sources**. Additionality models require sufficient context-specific data, including potentially qualitative information. SCGE and QSE models include prices across multiple markets; therefore, their data requirements may be higher.

Selection criteria

5.1.6 The suitability of the models varies by the **type** of schemes. In this context, proportionality implies that schemes of lower investment size should adopt simpler modelling approaches, such as Additionality and Reduced-form models, or adapt existing off-the-shelf models, where these are available. The larger the scheme investment, the more complex the models may be.

5.1.7 Whether a scheme is of national, regional or local **significance** is closely related to investment size. Schemes of national importance are best modelled in suitably specified SCGE models, whereas significant regional schemes may be assessed using less complex LUTI or QSE frameworks. For very large and complex schemes, combining different models may be considered. For example, one might use SCGE modelling for national impacts complemented by LUTI modelling to investigate local, place-based impacts. Modellers should note, however, that there is no consensus about how to appropriately couple different types of SEM and that great caution is needed to ensure modelling outputs do not become intractable.

5.1.8 The expected **magnitude of WEIs**, which the Strategic Case may indicate, should also be considered when identifying a proportionate SEM approach. If the importance of WEIs is low – relative to transport user benefits – basic SEMs should be the first option to explore. If WEIs are likely to strongly influence the scheme's Value for Money category, more complex, economically rooted models should be employed. The type of expected WEI should also inform the choice of model.

5.1.9 If significant unequal **place-based impacts**, such as widening or narrowing regional disparities, are expected, more spatially granular models are most suitable, notably LUTI and QSE models. SCGE models can only capture inter-regional place-based impacts that may arise from large-scale transport investments.

5.1.10 Modellers should consider the significance of **displacement** as defined in section 4.1.5. Additionality models account for displacement by down-rating gross GDP and employment by an adjustment value, which may be informed by context-specific information or evaluation evidence. Reduced-form models can account for displacement when their results are adjusted in a similar fashion. LUTI, SCGE and QSE models can account for displacement through appropriate market closure; for example, when they constrain the supply of factors of production at the national level while allowing for their relocations and price adjustments. To fully account for displacement effects, the models should be of national extent.

5.1.11 Where **multiplier effects** are of interest, the simple Additionality adjustments may be suitable; otherwise, models that adopt a general equilibrium framework are required.

5.1.12 Modellers should consider to which extent feedback effects on the transport network – or **transport external cost** – need to be represented. Such feedback effects are typically not included in basic SEMs and in general equilibrium models that treat a transport investment as exogeneous 'shock'. The two-way interaction between land use and transport are currently most developed in the field of LUTI models.

5.1.13 The models also vary with respect to their suitability to different **domains and transport modes**. For example, the ability and level of experience in relation to the different models varies regarding freight schemes. SCGE models may be best suited given their lineage in trade models. The flexibility of Additionality model may render them more suitable to incorporating freight. Other modelling types may require substantial modification, in view of the lack of established practice in the respective academic fields.

Considering the models' strengths and weaknesses

5.1.14 The model attributes viewed against selection criteria suggest general **strengths and weaknesses** of different SEMs. The chosen model's strengths and weaknesses should be explained in the Economic Narrative as part of the justification of the choice.

6. Model Specification

6.1 Introduction

6.1.1 Modellers should consider and evaluate several modelling aspects when specifying the Supplementary Economic Modelling. The extent to which these aspects have been addressed will inform the weight placed on the analysis in the scheme's Business Case. The Department recognises that it may not be feasible or proportionate to address all these aspects in equal depth for a given scheme.

6.1.2 This section covers the following important modelling aspects:

- economic assumptions and projections;
- the definition of schemes and the assumed geographic scope of their impact;
- important model parameters, such as elasticity values; and
- methods to derive social welfare impacts from modelled economic outcomes.

6.2 Economic Assumptions and Projections

6.2.1 By default, SEM should adopt the economic assumptions underlying TAG, which are summarised in subsequent paragraphs. Although these principles should be appropriate for most transport schemes, alternative assumptions may be tested and adopted. Greater confidence will be placed in analyses which are based on credible assumptions that are relevant to and appropriate for the context of the appraisal.

Economic assumptions

6.2.2 By default, TAG assumes on the **supply side** that the economy is in full employment, with wages assumed to adjust, and that, by default, government investment 'crowds out' private investment (see also TAG A2.1, section 2.1). For transport appraisal, this assumption implies that:

- an increase in public- or private-sector spending on goods and services cannot raise total employment but instead displaces labour from elsewhere in the economy; and
- the only means by which the government can raise total output is through supply-side measures, such as boosting productivity (TAG A2.4) or removing obstacles to people entering the labour market (TAG A2.3).

6.2.3 Transport investments should usually be modelled as supply-side interventions such that only supply-side effects are identified as **additional** benefits. The relevant TAG A2 units should be followed to appraise agglomeration benefits, labour supply effects and other WEIs. Any demand-side impacts identified in SEM, including local multiplier effects expressed in changes in employment or GDP, should not be counted as benefits, since these are assumed to net out at the national level.

6.2.4 TAG recognises **market failures and government distortions** in the market for goods, labour and land (TAG Unit A2.1). When developing SEM, the specific guidance should be followed, including on:

- positive externalities, such as productivity impacts or agglomeration benefits (TAG Unit A2.4);
- negative externalities, such as air quality and accidents (TAG Units A3 and A4.1);
- imperfect competition in markets for goods and services and land rationing (TAG Unit A2.2); and
- tax distortions (TAG Unit A2.3).

6.2.5 The Department recognises that TAG does not address some impact domains that may be relevant to some schemes. For example, there are no methods in TAG to capture the impact of transport schemes on trade, foreign investment and net migration. In such cases, the default economic assumptions should be followed as much as this is possible.

6.2.6 The assumptions underpinning SEM should be consistent with the transport model that appraises transport user benefits. Any departures from these assumptions or the economic assumptions stated in paragraphs 6.2.2 and 6.2.3 in the specification of the model or policy scenario should be explained and justified.

6.2.7 Greater confidence will be placed in analysis that:

- adopts the same assumptions in the SEM as those adopted in the transport model;
- considers displacement effects; and
- where applicable, presents empirical evidence on potential additionality as justified in the Economic Narrative.

Projections and scenarios

6.2.8 The results of SEM should be tested under different demographic and economic scenarios. TAG Unit M4 provides guidance on forecasting and uncertainty, including the specification of developments and transport schemes in the core (Do-Minimum) scenario and in alternative analytical scenarios.

6.2.9 Regarding macro-economic projections, greater confidence will be placed in models wherein projections are consistent with those informing the transport model, for example using estimates from TEMPro (the Trip End Model Presentation Program) or are based on other official Government projections.

6.2.10 Greater confidence will be placed in models where it can be demonstrated that the model structure is consistent with credible economic principles and best practice. All specifications should be consistent with relationships set out in TAG or authoritative empirical studies.

6.3 Geographic Scope and Spatial Resolution

6.3.1 The geographic scope should be national by default. If this is not appropriate for the specific appraisal case, the modelled area should be sufficiently large to capture a wide range of the expected impacts of the scheme, including displacement effects.

6.3.2 The spatial resolution – that is, the size of the zones for which the impacts are analysed – should be appropriate to the scheme's size. In principle, zones should be smaller in the vicinity of the scheme. Modellers should consider the common trade-off between spatial granularity and data availability and the associated uncertainty involved in any spatial data disaggregation.[6]

6.3.3 SEMs must specify the same transport improvements as the transport models. Where the identical specification of the transport investment to the same level of detail is not possible, for example due to different levels of aggregation, modellers should explain how it has been ensured that representations of the transport improvements are consistent with those of the transport model.

6.3.4 When specifying the geographic scope or spatial resolution, modellers should also consider:

- any other planned interventions the scheme may interact with; and
- any complementary interventions that are necessary to leverage the full expected benefits of the investment, for example the granting of planning permission by local authorities or policies to develop the skills of the local workforce.

6.3.5 The consideration of complementary interventions is particularly important for regeneration and transformational schemes. However, if the complementary

[6] See also the more general discussion of handling transport and economic data in Appendix C of TAG Unit A2.4.

investment exists in the Do-Minimum scenario, standard appraisal guidance should be followed. Further information on complementary interventions can be found in TAG units A2.1 and M4.

6.3.6 Greater confidence will be placed in models where:

- the geographic scope of the SEM aligns with the scope used in the model to calculate transport user benefits;
- the transport accessibility improvement has been estimated using a well-specified transport model, that is, the transport modelling is consistent with guidance in the TAG Modelling units; and
- the same estimates of the transport accessibility improvements, used to calculate transport user benefits, are specified in the SEM.

6.3.7 Special attention should be paid to the assumptions underpinning dynamic adjustments in both static and dynamic models. **Anticipatory effects** based on a high level of foresight may overestimate benefits and require adjustments. Since there is lack of evidence on these dynamics, the choice of any adjustments should be clearly explained and subject to sensitivity testing.

6.4 Model Parameters

Defining model parameters

6.4.1 All model parameters, such as elasticities, expenditure shares and level of agent foresight, where applicable, should be:

- consistent with the default assumptions set out elsewhere in TAG, unless it can be justified that alternative estimates are more robust or up to date;
- robust, that is, insensitive to outliers and associated with narrow confidence intervals;
- empirically supported and derived from statistically significant results;
- plausible in view of results from other empirical studies; and
- where possible, validated using recent data or studies from the UK.

Model parameters should be used in equations that have the same functional form as the original empirical models estimating these parameters.

6.4.2 Special attention should be paid to the assumptions underpinning dynamic adjustments in both static and dynamic models. **Anticipatory effects** based on a high level of foresight may overestimate benefits and require adjustments. Since there is lack of evidence on these dynamics, the choice of any adjustments should be clearly explained and subject to sensitivity testing.

Estimating model parameters

6.4.3 Where econometric estimation has been undertaken, it is necessary to demonstrate that estimates are not influenced by common types of **bias**, including omitted variable bias, endogeneity and multicollinearity. Common techniques to address such issues include the specification of fixed effects or, where available, control or instrumental variables.

6.4.4 **Omitted variable bias** may occur where unmeasured area-specific characteristics influence economic activity. For example, when estimating agglomeration elasticities, it is necessary to control for differences in average skills between regions, since highly-skilled people often move to areas with higher effective densities.

6.4.5 **Endogeneity** may occur where schemes are placed because specific economic impacts were perceived to be more likely. For example, areas with higher access to economic mass (ATEM) may experience larger transport investments. Therefore, the coefficient on ATEM may not accurately represent the causal impact of the transport scheme on economic activity.

6.4.6 **Multicollinearity** may occur if highly correlated independent variables have been included in the regression. For example, effective densities by different modes of transport are highly correlated with each other and thus their respective coefficients may respond erratically to small changes in the model or the data. This issue may be addressed by testing for multicollinearity and improve the independent variable selection accordingly.

6.5 Deriving Social Welfare Impacts from Economic Outcomes

6.5.1 Where SEM is used to estimate a scheme's impact on economic outcomes, such as GDP or employment, it is necessary to calculate the corresponding national welfare impacts. Figures informing the Value for Money assessment and non-welfare metrics should be estimated on a consistent basis.

6.5.2 Approaches which might be used to convert economic outcomes into welfare estimates, may be divided into 'bottom-up' and 'top-down' approaches. Having thus obtained welfare estimates from SEM, modellers must assess whether these impacts are additional to other appraised welfare impacts; that is, they can be added together without double-counting.

6.5.3 The **bottom-up approach** is most appropriate when estimating those WEIs that are recognised in TAG Unit A2.1. Table 2 summarises how SEM may be used to obtain bottom-up estimates for each of the WEIs currently in TAG. Where the bottom-up approach is adopted, it is necessary to ensure that the welfare estimates of the SEM are not added to the standard estimates obtained from following the guidance in these TAG units in order to avoid double-counting of benefits.

6.5.4 In the **top-down approach** to estimating a scheme's impact on social welfare, the estimated national GDP effect is converted to a measure of national social welfare by adding and subtracting other welfare impacts, such as social and environmental impacts. Some of the potential non-financial welfare impacts associated with increased GDP may include:

- Transport external costs (see also TAG Unit A2.2) – an increase in production may result in increased commuting and business travel, which may result in welfare losses due to increased congestion, crowding, air pollution, noise or accidents;
- Disutility from labour supply effects – GDP increases due to people moving from inactivity to employment in response to the transport scheme may be accompanied by welfare losses from a) people having less leisure time and b) the disutility of work itself.
- Disutility from movement to more/less productive jobs – GDP increases due to people moving and taking up more productive, better paid jobs in response to a transport improvement may be accompanied by welfare losses, such as the financial and social costs of moving, differences in living costs and amenity values of different locations.

Table 2 – The bottom-up approach to estimate wider economic impacts (WEIs)

WEIs	Bottom-up method for estimating WEIs
Output effect with imperfect competition (TAG A2.2)	Estimate context-specific mark-ups, i.e. those differing from the default 10% uplift, and apply them to user benefits for business and freight travellers.
Labour supply impacts (TAG A2.3)	Estimate the tax wedge: quantify the number of people entering employment using SEM; estimate the associated tax wedge based on all jobs being paid at 69% of the mean wage per worker in their area and a tax wedge of 40%.
Movement to more/less productive jobs (TAG A2.3)	Estimate the tax wedge: quantify the relocation of jobs can be estimated using SEM; estimate the associated tax wedge based on the national mean GDP associate with the relocated workers, the zonal productivity differential and a tax wedge of 30%.
Static clustering effects (TAG A2.4)	Estimate static clustering using simple Reduced-form modelling; no adjustment required.
Dynamic clustering effects (TAG A2.4)	Estimate benefits as the productivity gains in locations experiencing inflows of jobs less productivity losses in regions experiencing job outflows; exclude welfare benefits associated with movement to more or less productive jobs.

6.5.5 Disutility or welfare losses arise from the **opportunity costs** associated with the GDP-increasing economic activity. In general, opportunity costs must be significant, since otherwise the individuals may be presumed to have relocated or entered work without the transport scheme. One approach to quantify these opportunity costs is to assume that they equal the welfare gain from increased disposable income of people moving to more productive jobs or entering the labour market. This implies that there is no private welfare gain arising from these decisions. Consequently, the welfare benefits are assumed to equal the associated increase in tax.

6.5.6 When using the top-down method, it is necessary to determine a) to which extent the welfare benefits are **additional** to level 1 and 2 impacts; and b) whether these impacts can be included in the appraisal as level 3 benefits without double-counting. Inclusion of these level 3 benefits in the scheme's Value for Money assessment will need to be decided on a case-by-case basis.

6.5.7 The top-down approach may be appropriate where a scheme is expected to generate wider economic benefits **not covered in TAG**, for example tax gains associated with increased trade or multiplier effects. Nevertheless, the top-down approach may over-estimate a scheme's welfare impacts, if relevant welfare losses are omitted from the appraisal. Therefore, greater confidence will be placed in welfare estimates obtained using the bottom-up approach.

7. Model Validation and Assurance

7.1.1 This section sets out the main elements of validating and quality-assuring SEM. More detailed guidance can be found in TAG Unit M3.

7.1.2 All models should be validated and quality-assured. The Department recommends that scheme promoters obtain the data, code and full technical documentation of the SEM, especially where third parties have been commissioned.

Sensitivity testing

7.1.3 Sensitivity testing should be undertaken on all of the key assumptions underpinning the model and key model specification, as described in the previous section 6. The assumptions and specifications may include:

- different assumptions regarding employment levels;
- different assumptions about displacement;
- different assumptions about foresight and anticipatory effects;
- macroeconomic projections, including population growth and GDP per worker;
- traffic growth projections (see TAG Unit M4);
- assumptions informing the modelled core scenario (see TAG Unit M4); or
- alternative model parameters based on confidence intervals or estimates from other studies.

7.1.4 In addition, modellers should observe any recommendations on sensitivity testing that are specific to the chosen modelling framework. Some of these are indicated in paragraphs 4.3.18, 4.4.18 and 4.5.18 for LUTI, SCGE and QSE models respectively. For these advanced supplementary economic models, it is common practice to conduct sensitivity testing on:

- different plausible elasticity values used in behavioural functions;

- assessing outcomes of interest under different market clearing and macroeconomic closure settings; and
- if feasible, the impact of probabilistic variation of all parameter values using 'bootstrapping' techniques.

Modellers should consult the current relevant literature to adopt evolving best practice.

7.1.5 Where applicable, the impact of different market closure conditions should be tested in different combinations or at different scales. For example, where a transport scheme is estimated to affect labour supply, the results may be tested under different rules of other factor market closures at national or regional levels.

7.1.6 Greater confidence will be placed in analysis where sensitivity testing has been undertaken on all key assumptions informing the analysis, and the ranges underpinning this analysis have been informed by evidence.

Realism tests

7.1.7 Realism tests assess whether the outputs of a model are plausible. For example, analysis might be undertaken to demonstrate that the model produces

- outputs that are consistent with hypotheses set out in the Economic Narrative;
- outputs that are plausible in view of other evaluation evidence, for example estimates from Melo et al (2013) or What Works Centre for Local Economic Growth (2015);
- accurate predictions of past levels of economic activity, for example by using backcasting, where feasible; and
- outputs approximately equal to those estimated following guidance in the TAG A1 and A2 Units under the same assumptions.

7.1.8 Greater confidence will be placed in analysis that has been subject to realism testing and where the estimated impacts vary credibly with plausible changes in the modelling assumptions.

Assessing consistency with conventional appraisal methods

7.1.9 Modellers should carefully examine any differences between the outputs arising from departures from TAG's default assumptions, modelling principles and parameter values as set out in the TAG A1 and A2 units. To achieve this, modellers may first configure the SEM such that they embody the default assumptions underpinning the standard methods used to estimate transport user benefits or WEIs. Then, modellers may gradually relax the assumptions, compare the outputs of different model runs and identify the modifications that explain most of the differences.

7.1.10 Greater confidence will be placed in SEM where the estimates of the standard methods could be reproduced, where differences due to alternative model specifications have been explored systematically and where they have been demonstrated to be credible. For information on profiling SEM outputs up to the end of the appraisal period after the last modelled year, see TAG Unit A1.1.

Independent Review

7.1.11 If more complex types of SEM are used and the departure from standard TAG methods is significant, the models should be independently peer reviewed. The peer review should evaluate to which extent

- each of the model specification aspects presented in section 6 have been addressed;
- the model results can be regarded as plausible and credible;
- sensitivity and realism testing has been undertaken satisfactorily; and
- the models can be regarded as consistent with conventional appraisal methods.

7.1.12 In addition, the peer review should describe any major shortcomings of and uncertainties associated with the analysis. Any other issues that were identified as significant should be explained, too.

7.1.13 If it seems feasible and proportionate, the SEM may be supported by independent expert advice at the stage of model development.

8. Reporting Supplementary Economic Modelling

8.1.1 It is critical that modelling evidence of the potential impacts of a transport scheme is presented and explained in a transparent and consistent manner in the Business Case. Therefore, all SEM choices and specifications should be justified and the credibility of the analysis should be demonstrated.

8.1.2 The Economic Narrative (TAG Unit A2.1) should explain and justify:

- the decision and rationale to adopt SEM as detailed in paragraph 2.1.11;
- how the model was selected according to the criteria set out in section 5, including the chosen model’s strengths and limitations; and
- the use of any context-specific or other empirical evidence related to displacement and multipliers.

8.1.3 All aspects of the model specification described in section 6 should be reported in the Economic Impacts Report following the guidance in TAG Unit A2.1, Section 6. The Economic Impacts Report should be included as an annex to the

Economic Case and provide details on all functions, equations and parameter values that underly the measures reported in the Economic Case.

8.1.4 Regarding the economic assumptions, the report should describe and explain:

- any different economic assumptions to those adopted in TAG and how they differ, including how displacement effects have been accounted for (see paragraphs 6.2.1 to 6.2.7);
- the assumptions underlying the Do-Minimum scenario (paragraph 6.2.8);
- all of the key projections underpinning the model, their sources and whether they are consistent with the assumptions informing the transport model (paragraph 6.2.9); and
- any projections estimated by the project team, including the methodology and assumptions underpinning these (paragraph 6.2.10).

8.1.5 Regarding definition and scope of the scheme (section 6.3), it is necessary to explain:

- how the geographic scope of the modelled area and the sizes of modelled zones have been decided and defined;
- what assumption informed any spatial data disaggregation that has been performed;
- how the transport accessibility improvement has been estimated, if this differs from the transport model;
- how the transport accessibility improvement has been put into the SEM, such as the change in generalised travel costs, user benefits or travel time savings;
- whether the transport accessibility improvement input is consistent with that used to estimate transport user benefits;
- where applicable, whether analysis has been undertaken to iteratively run the land-use model with the transport model and, if so, how many times; and
- where applicable, how any complementary interventions have been modelled.

8.1.6 All mathematical parameters and relationships (section 6.4) underpinning the SEM must be described and explained. In addition, all the key parameters and the results of their use in the base year calibration, where applicable, and model validation should be reported. The reporting should include sources of evidence, indicating the level of uncertainty associated with the estimates. The Uncertainty Log in Appendix A of TAG Unit M4 may serve as a template for how this information could be presented.

8.1.7 Where SEM has been used to estimate a scheme's impact on economic outcomes (section 6.5), such as GDP or employment, it is necessary to report the corresponding national welfare impact. The details of welfare and non-welfare measures and methods of the conversion of the latter should be reported following the guidance provided in TAG Unit A2.1, section 7. Welfare and non-welfare estimates of SEM must also be reported in the Economic Case.

8.1.8 Regarding model validation and assurance (section 7), it should be documented:

- what sensitivity testing has been undertaken;
- what realism tests have been undertaken; and
- whether and how the SEM has been independently peer reviewed.

Any independent peer review of the model should be made available to the Department and it may be published alongside the modelling report, if appropriate.

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Appendix A: Correspondence between National Welfare and GDP Impacts in TAG

	Welfare Impact	GDP
User benefits (A1.3)	User benefits from business, commuting and leisure trips	Business user benefits plus user benefits from price reductions[1] for non-work travel
Induced Investment (A2.2) Dependent Development	Land Value Uplift (LVU)	LVU + 2 x development costs for residential development[2] Development costs only for commercial development. All estimates need adjusting for additionality.[3]
Induced Investment (A2.2) Output Change in Imperfectly Competitive Markets	13.4% of Business User benefits (incl. reliability benefits)	13.4% of Business User benefits (incl. reliability benefits)
Employment Effects (A2.3) Labour Supply Impacts	40% of change to GDP (tax revenue)	GDP (= welfare impact / 0.4)
Employment Effects (A2.3) Move to More/Less Productive Jobs	30% of change to GDP (tax revenue)	GDP (= welfare impact / 0.3)
Productivity Impacts (A2.4) Agglomeration Economies (incl. static and dynamic clustering)	Agglomeration Impacts	Agglomeration impacts
Accidents (A4.1)	Based on VPF and injury values	15% of road accident impacts[4] Other modes: 30% of fatal injury impact, 10% of serious and 15% of slight
Physical Activity (A4.1)	Benefits calculated using the AMAT tool	Absenteeism benefits, plus 30% of the reduced mortality benefits
Air quality (A3)	Welfare impact taken from Defra AQ damage costs	20% of welfare impact[5]

This table is reproduced from TAG Unit A2.1, section 4. Please refer to that unit for more context.

Notes:

1 Price reductions refer to changes in market prices paid for travel, for example petrol prices, rail fares, or road tolls. It may not always be proportionate to split out the different elements of the user benefits calculation, in which case commute and other non-work user benefits should be assumed to not contribute to GDP at all.

2 Strictly speaking the GDP impact is the sum of development costs and the annual flows of housing rents (actual or imputed). These rental flows are quantified using existing information typically available from TAG appraisals. If alternative quantifications are needed, consult TAG Unit A2.1.

3 The same additionality value should be used for both GDP and welfare.

4 Based on the percentage of the welfare cost associated with each injury type (fatal, serious, slight and damage only) attributable to gross output losses.

5 Based on the Defra impact pathway guidance for air quality appraisal, specifically the 'productivity' and 'chronic mortality' rows. For further information, consult TAG units A2.1 and A5.4).

Appendix B: Further Reading

On Basic SEMs:

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On LUTI models:

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