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REMOTE WORKING AND AGGLOMERATION

Report

Prepared by David Simmonds for the Department for Transport

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SUMMARY

This report considers how the agglomeration benefits of transport schemes may be affected by remote working, i.e. by workers working at home (or another place of their choosing such as a café) when they have a conventional out-of-home workplace to which they could commute, and to which "traditionally" they would have commuted every working day. Remote working had been increasingly prevalent for many years before it briefly became the dominant mode of working during the Covid-19 pandemic. Since the pandemic has receded it has remained much more significant than before, though is not clear that a "new normal" has been or will be reached.

The report first argues that consideration of these linkages requires the analysis of "agglomeration" to be broken down from a single effect per sector as defined in TAG into distinct "micro-foundations" or "micro-effects", because of the different ways in which remote working may impact upon these.

Drawing on the existing literature, these "micro-foundations" can be grouped into

- sharing effects
- matching effects
- learning (knowledge) effects.

The report proposes that different effects within these categories require different measures of access to economic mass which themselves take account of remote working. It suggests that some micro-effects – those that depend largely or entirely on freight transport – will be unaffected by remote working (at least so long as the firms involved manage any possibilities of remote working so that goods can be produced, delivered and used as efficiently as before). In contrast, labour market matching, which has traditionally been about "who commutes to which job", is very directly affected by remote working, though the consequences are not simple or self-evident. Some of the other micro-effects are more complex again.

A small but non-trivial numerical model of a hypothetical British city has been set up to test the consequences of these suggestions. This uses different measures of access to economic mass (A2EM) for different micro-effects, and different sensitivities to change in A2EM for each sector; the A2EM specifications and the sensitivities to them are themselves all hypothetical, though consistent with existing evidence on overall sensitivities. Experiments with this model indicate that increased levels of remote working will generally tend to reduce the agglomeration benefits of transport improvements, though to different degrees for different types of schemes. The experiments also suggest that the reductions may change if land-use distributions respond significantly to remote working; the directions of change will depend on the form that the land-use responses take.

In the light of the limited evidence available so far, the conclusions of the study suggest possible adjustments to TAG agglomeration benefit calculations:

- for schemes focussed on commuter travel to major office centres, to reduce the TAG agglomeration benefit for producer services (only) in proportion to the expected level of remote working (with no change to the results for the other sectors);
- for other urban schemes, to make a smaller reduction (i.e. by 20% if 20% of producer service workers are expected to work remotely on the average working day);

- for schemes with a significant element of improvement for long-distance commuting, to consider the possibility that the agglomeration impact will be increased.

The conclusions also discuss the range of serious challenges to be faced in further empirical research to obtain better evidence.

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ABBREVIATIONS

Abbreviation	Meaning
A2EM	access to economic mass – see Figure 4-1 (page 25)
A2F	access to facility (special case of A2EM)
CBD	Central business district – in particular, zone 1 of the hypothetical city model (see Figure 6-1, page 46)
CONST	Construction sector, as defined in TAG
CSERV	Consumer services sector, as defined in TAG
D&P	Duranton and Puga paper – see page 18
DfT	Department for Transport
GDP	gross domestic product
GVA	gross value added
L&T	Laird & Tveter report – see page 13
LUTI	land-use/transport interaction
MANUF	Manufacturing sector, as defined in TAG
ONS	Office for National Statistics
OTHER	Other sector, i.e. all employment not in MANUF, CONST, CSERV or PSERV
PSERV	Producer services sector, as defined in TAG
PT	public transport
RW	remote working – see definition in section 2.3
SOC	Standard Occupational Classification
SP	stated preference
TAG	Transport Appraisal Guidance (DfT)
WPC	workplace parking charge – in particular, the modelled scheme defined at 9.2.4

1 INTRODUCTION

1.1 Objectives

1.1.1 This Report has been prepared by David Simmonds, working as Allanfield Consulting, for the Department for Transport.

1.1.2 The brief for the study set out the Department's wish "to further its understanding of how agglomeration impacts have been impacted by the COVID-19 pandemic and the resulting legacies of increased homeworking, behavioural change and potential for land-use change in the longer term (which may affect the pattern of effective density)". It called in particular for "a theoretical case study (i.e. worked example, but not real-life) which illustrates the potential impact of COVID-19 – and the associated economic and behavioural changes".

1.1.3 As the objective was clearly to improve future appraisals, not to review the past, the focus of the study has been entirely on the longer-term implications of the changes in working, commuting and living arrangements that were highlighted by experience during the pandemic, not on impacts during or immediately after the pandemic.

1.1.4 The scope and structure of the report are explained in chapter 2.

1.2 Acknowledgements

1.2.1 The author is grateful to the Department for the opportunity to carry out this interesting piece of work, and in particular to the DfT project officers, Iven Stead and Milla Hamunen, for their helpful guidance and comments throughout the project. Any errors of commission or omission remain the responsibility of the author.

2 APPROACH TO THE STUDY

2.1 Introduction: the Laird and Tveter study

2.1.1 The present study was commissioned to build on the conclusions of an earlier one, carried out for the Department by Laird and Tveter[1]. The following paragraphs summarise the conclusions of that study (referred to from here on as L&T).

2.1.2 The L&T study started a process of considering how homeworking, which greatly increased during the Covid19 pandemic, may impact on the agglomeration benefits that transport projects may deliver. Their report shows that homeworkers during the pandemic were predominantly made up of urban-based, white collar, well-educated, service sector employees. The pandemic (or the measures taken in response to it) increased the proportion of homeworking in each occupation and sector, but aside from - possibly - administrative and secretarial occupations, it did not significantly alter the demographics of the homeworker. The evidence from the pandemic indicates a potential upper ceiling to the numbers of homeworkers of around 60% to 65% of the workforce in the occupation that are most suitable for homeworking[2]. L&T estimate that over the whole workforce it is likely that only between 40% and 50% could work from home[3].

2.1.3 L&T note that the literature contains a great deal of speculation about the future of homeworking and how it may change the hierarchy, shape and function of cities. However, from stated intentions data it appears that homeworking is seen by the majority of the (pandemic homeworking) workforce to be something they only want to do some of the week – commuting on the other days. This would imply that cities and city centres will continue to remain important in the future, but that there will likely to be some changes in the land and transport markets as a consequence of more homeworking. What happens in the land and transport markets will be interrelated.

2.1.4 Aside from impacting on where people work, both in terms of where their non-home workplace is and how often they go there, it is suggested that homeworking may modify the scale of the external economies of urban scale that give rise to agglomeration benefits. L&T found little empirical evidence that could be drawn on regarding the influence of homeworking (or digital connectivity) on agglomeration economies. What data exists on agglomeration elasticities is very much at an aggregate level, and cannot be disaggregated beyond sectors and countries. The evidence on the micro-mechanisms that underpin agglomeration economies is very

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[1] Laird, J and E Tveter (2021): *Agglomeration under Covid*. Final report to DfT, available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1079102/agglomeration-under-covid.pdf. The following paragraphs are mostly an edited version of their abstract.

[2] The top three groups for homeworking were identified as Managers, Directors and Senior Officials; Professional Occupations; and Associate Professional and Technical Occupations; all of which had significant levels of homeworking before the pandemic. The fourth category is Administrative and Secretarial Occupations, for whom homeworking increased most dramatically, from very levels, during the pandemic. Note that homeworking in the data used may include people working at or from home with no other workplace, who would not fit into the present definition of “remote working”.

[3] This rather high-seeming estimate is based on extrapolation from US data, and supported by the results of a UK survey carried out for DfT (Covid-19 Public Polls Transport Tracker. Working from home evidence. February 2021).

much concerned with demonstrating their relevance as sources of agglomeration economies, rather than identifying the proportion by which each mechanism contributes to agglomeration. This does not permit the evidence to be used to estimate the potential for homeworking to enhance or erode the scale of agglomeration economies. The only form of disaggregation possible is between the static (matching and sharing sources) and dynamic mechanisms (learning sources). Homeworking may enhance matching mechanisms (by lowering average commute costs), but learning mechanisms dependent on face-to-face contact may be damaged or lost altogether. However, this is conjecture as evidence is non-existent on the impact of step changes in interaction costs.

2.1.5 Laird and Tveter considered it unlikely that homeworking would negate the existence of agglomeration economies, though it could alter the productivity levels in cities and alter the change in productivity due to transport investments. Cities have been remarkably resilient to the digital age, and in fact are becoming increasingly important – and effect attributed to their role as "centres of ideas". Households also like to locate in cities for the amenities on offer. To understand the potential impact of a step change in homeworking, as induced by the pandemic, on agglomeration benefits in a transport appraisal some research is needed; this needs to be multi-pronged.

2.1.6 One component of the work, given the age of the current agglomeration parameters (agglomeration elasticity and decay parameter) is to better understand the role of transport costs in the access to economic mass (A2EM) function[4]; L&T considered updating those parameters the most important aspect of research to pursue. The second component is the potential impact of homeworking on agglomeration benefits, which could be explored in the short-term using scenario analysis based on estimates of homeworking, land use change and transport cost changes. In the longer term, deeper consideration will need to be given to consistency across the different facets of the appraisal such as other wider impacts in TAG, the land use inputs used as standard in appraisals and the treatment of uncertainty in these inputs.

2.2 <u>Connection to the present study</u>

2.2.1 The present study set out to deliver a version of the scenario analysis suggested by L&T as the short-term means of estimating the potential impacts on agglomeration benefits. The proposal for this study also noted some issues to which L&T gave limited attention:

- distinguishing remote working (people who could commute, but don't) from other people working mainly at or from home
- the ways in which remote working will play out: whether as a free choice for the worker, or decided by their employer;
- the possibility that new methods will be needed e.g. their discussion of the A2EM function seems to envisage recalibration rather than the necessity for

[44] Access to economic mass (A2EM) is in broad terms a measure of agglomeration for one particular place or zone: how many jobs (or other units of economic mass) are in the economy, weighted by how easy it is to interact with them (how easily they can be reached). The concept is discussed further in chapter 4.

a different function or functions reflecting the mechanisms determining the consequences of remote working in different sectors/occupations.

2.2.2 The first two of these are matters of definition, considered in the following section. The third point is the main focus of the present study, as introduced in section 2.4.

2.3 Remote working

2.3.1 The distinction between what we call "remote working" and the broader category of "working at home" is important. The discussion here is about "remote working" or "remote workers" meaning people who could commute to a conventional out-of-home workplace but instead work from their home (or somewhere near their home, such as a coffee shop). These are different from the large and numbers of people who work entirely at or from home, and have no other fixed workplace. The working at or from home category includes some people who – if they had a non-home workplace – would readily fit into the demographic of the typical homeworker (self-employed independent consultants in modelling and appraisal, for example), but it also includes many very different occupations: farmers who live on their farm; independent taxi drivers; artists and craftsmen who work in their studio or garden shed; and independent building tradesmen who have no regular workplace other than their van and perhaps a store. These workers are an important part of the economy, and changes in their numbers may also have implications for transport and for agglomeration; but they are separate from the remote working category which increased so rapidly during the pandemic, and for whom there is a choice between working at home or commuting to a workplace.

2.3.2 That choice between working at home or commuting may be made in different ways: at one extreme, employees may be given a free choice of when and how often to come into the workplace; at the other, employees may be required to work in the office on some days and not on others, or rationed (via a "hot desk" allocation system) in how often they can come in. In between, there is the possibility that firms will offer some flexibility together with a requirement to be in the office on certain pre-specified days, with work being organized so that activities involving interaction between staff are concentrated on the in-office days, with the other days being used more for "solo" work. It is not clear which of these patterns will predominate, and it may well be that different firms (or different groups within firms) will settle on different arrangements. (That said, it seems – anecdotally – that firms which initially planned draconian reductions in office space (80% less space, workers in the office once a week) are now aiming at much less dramatic changes.)

2.3.3 These different patterns of remote working would have differing consequences for transport demand and for agglomeration effects. The idea of maximising interactions in the office clearly relates to enhancing productivity through within-firm interaction. How all these (and remote working generally) turn out in terms of between-firm interaction is discussed further in the following chapters. The present study does not attempt to go into the detail of these alternatives, but does set out calculations that respond to an explicit "level of remote working" variable. This is simply the proportion of workers with an out-of-home workplace to which they might commute who work remotely on an average working day. This will of course vary significantly by day of the week (present evidence is that remote working is most popular on Fridays) and perhaps also by season[5].

2.3.4 Note that the definition of remote workers (repeated below for reference) includes workers who work entirely from home, and at the other extreme workers who commute almost every day except when they have an exceptional need to stay at home (e.g. to let the plumber in).

Box 2:1 Definition of remote working

> Workers who have a workplace away from their home at which they could work but who, more or less often, work at home, or from another location that the worker chooses as an alternative to working at home. The pattern and frequency of remote working may be a choice exercised by the worker, a requirement of the employer (e.g. combined with a hot-desk rationing of office space), or a mixture of the two.
>
> Remote working implies that when (or if) the worker goes to the workplace, it is in their own time and at their own expense. If their employment contract or self-employment arrangements mean that travel to the workplace is in working time and at the firm's expense, they are not a remote worker.

2.4 Mechanisms and measures

2.4.1 The third point made regarding the L&T work is the suggestion that more sweeping changes to the ways in which we measure agglomeration, and estimate the effects of changes in agglomeration, are needed, rather than the recalibration of existing functions which seems to be the main suggestion from L&T. At the beginning of the present study it was agreed to look, if necessary somewhat speculatively, at such changes to the ways in which agglomeration effects are calculated, and to consider the implications. This report is therefore organized as follows.

2.4.2 Chapter 3 starts to identify potentially relevant changes by reviewing the "micro-foundations of agglomeration" as listed by L&T and previous authors.

2.4.3 Chapter 4 considers a general number of points about agglomeration functions and their potential use in productivity change calculations.

2.4.4 Chapter 5 brings together the discussions from the preceding two to propose specific functions for representing each of the micro-foundations.

2.4.5 Chapter 6 describes the hypothetical city used to test these new functions, and the model of the city used for the analysis. Chapter 7 reports the coefficients chosen to implement the new functions. The following three chapters then report on results in terms of

- the impact of remote working on agglomeration-related productivity (chapter 8),

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[5] A previous study discussed this without finding any evidence (yet). The author's hypothesis was that if remote working choices are made by the worker, it will generally be more popular in mid-winter (to avoid commuting in bad weather) and in mid-summer (both to avoid commuting in very hot weather, and – for those with the option - to enjoy working in the garden or park).

- the impact of remote working levels on the agglomeration benefits of hypothetical transport interventions (chapter 9), and
- how those benefits change under different scenarios for land-use responses to increased remote working (chapter 10).

2.4.6 Chapter 11 then draws out some conclusions in terms of further work that may help to substantiate – or to modify or refute – the suggestions in this study regarding the workings and modelling of agglomeration mechanisms and the effects of remote working on those mechanisms. It also sets out potential short-term adjustments to existing appraisal calculations that might be appropriate in the light of the results reported here.

3 MICRO-FOUNDATIONS OF AGGLOMERATION EFFECTS

3.1 Introduction

3.1.1 This Chapter reviews the proposed micro-foundations of agglomeration effects, starting from the existing literature, in preparation for considering how these could be modelled and, in particular, what measures of A2EM may be appropriate to these different mechanisms. The starting points are the various micro-foundations listed in the L&T paper[6] – which in turn are referenced to Duranton and Puga (2004)[7]. Some points in the following are drawn from a pre-print of the latter paper[8], referenced here as D&P.

3.2 Sharing effects

3.2.1 "Sharing" is an established term for these micro-foundations but seems a potentially misleading one. Note that the "sharing" micro-foundations don't necessarily imply any of the goodwill or conscious sharing that one would expect to find in a group of friends sharing dinner or a bottle of wine.

3.2.2 L&T, following D&P, identify four effects (to which we give a numbering S1, etc):

- higher productivity from availability of indivisible goods and facilities (S1);
- higher productivity from more reliable or more appropriate supply of inputs, resulting from a larger number of potential suppliers (S2);
- higher productivity from individual worker specialisation permitted by a larger market for the service or skill the worker supplies (S3); and
- higher productivity from reduced risk and from more specialised demand for the products offered (S4).

3.2.3 To these we add two further possibilities:

- higher productivity from amenity value of services used by staff around their workplace (S5); and
- higher productivity from indivisible facilities enjoyed by residents in general (not related to workplaces) (S6).

3.2.4 We consider these in turn.

Higher productivity from availability of indivisible goods and facilities (S1)

3.2.5 It is rather difficult to think of relevant examples of "indivisible goods"– especially ones that could be both indivisible and "shared". The rest of the discussion gets

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6 See in particular Tables 3-1 to 3-3 and 4-1 to 4-3.

7 Duranton, G & D Puga (2004): Micro-foundations of urban agglomeration economies. Chapter 48 in: Henderson, J. V. & J-F Thisse (eds.) *Handbook of Regional and Urban Economics*. Elsevier.

8 Duranton, G & D Puga (2003): *Micro-foundations of urban agglomeration economies*. National Bureau of Economic Research Working paper 9931. Available at http://www.nber.org/papers/w9931

round this by concentrating on redefining the subject as "goods or services produced by indivisible facilities", and thus concentrating on the facilities.

3.2.6 D&P's example of an indivisible facility is an ice hockey rink (2003, p4). Any benefits to firms from a city having an ice rink (apart from those supplying it) would seem to be indirect – through the benefits to residents – rather than direct to the firm's operations, and therefore to fall into S6 (see below) rather than S1.

3.2.7 Our preferred example of "goods or services produced by indivisible facilities" is the provision of commercial air services, particularly international flights, by a major regional airport[9]; airline and airport economics tend to ensure that there is one such airport, at least for more business-oriented services, per region. The level of goods and services supplied (e.g. the variety and frequency of air services, and possibly their fare levels) may change with the size of the economy it serves; so whilst the facility may be indivisible and (normally) immobile, its value to the regional economy is not necessarily constant but may show positive feedback effects.

Higher productivity resulting from a larger number of potential suppliers (S2)

3.2.8 This refers to higher productivity resulting from more reliable or more appropriate supplies of inputs, those better supplies themselves resulting from a larger number of potential suppliers. The point about "more appropriate" supplies is not in L&T or D&P but seems important – "getting the best components from suppliers" is the equivalent of "finding the best worker for the job" (see Matching, below).

Higher productivity from individual worker specialisation permitted by a larger market for the service or skill the worker supplies (S3)

3.2.9 There would seem to be three separate issues here, about

- **why** worker specialisation occurs;
- **how much** workers choose to specialise; and
- **where** they locate once they can offer specialist skills.

3.2.10 Taking **why** first: specialisation may come about through the employer's choices (telling a worker to focus on doing one thing well) or the worker's choices. Employers' choices about specialisation are likely to reflect either the specialisation or the size of the firm (or establishment), which in principle are out of scope here as internal effects; so we focus on workers' choices as more of an externality.

3.2.11 Choices about **how much** to train and specialise start even before the worker enters the labour market, with the decision of whether to leave school at the earliest possible date, or to continue. The resulting commitments cover an extremely wide range, from a few days' study up to years of intensive study and practice; we are more concerned with the latter. It seems reasonable to suggest a distinction (two points on a continuum) between

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[9] We emphasise international flights because when we are considering agglomeration effects across the whole country, domestic flights will be part of the internal transport system. In contrast, in the hypothetical city example used later in this report, we consider only that city region, with the airport as a special point of access to the rest of the country and the rest of the world; domestic as well as international services would contribute to its importance.

- highest levels of specialisation (roughly the "professional/managerial" occupations at Level 4 of SOC 2000) i.e. involving substantial study, where the worker expects to have a wide choice of where to work, and probably also expects to have to move between regions or countries to study and to gain experience;
- medium-high levels of specialisation (roughly Level 3 of SOC 2000 - in particular, the "skilled manual" occupations (in engineering, construction, etc); to a lesser extent also Level 2) i.e. where the worker doesn't expect or need to have to move far to study and work, though he/she may gain more opportunity to do so.

3.2.12 The highest-skill group, which probably overlaps largely with Florida's "creative class"[10], exercises a high degree of choice (by virtue of high incomes) and is likely to be attracted to cities by the amenities they offer as well as by the career opportunities they offer. Likewise, their choice of residential location within cities is likely to be strongly influenced, budgets permitting, by housing quality and easy access to amenities.

3.2.13 The medium-skilled group are more likely to be influenced by what training is available locally, and how accessible it is; more likely to remain in the same city; and more likely to locate nearer to the opportunities for their work if they can afford to do so (because their commuting costs are more significant relative to incomes). The "skilled manual" part of these jobs are less likely to be located in city centres, which will to some extent help housing affordability, though it may also limit public transport alternatives for access to work.

3.2.14 The possibility of remote working in particular occupations may make people more willing to specialise within those occupations because remote working will give them a greater choice of employers looking for their specialism; it may make it possible to reach specialised employment from a residential location where such jobs are inaccessible for conventional commuting. There may be less incentive for this in large urban centres, where a choice of employers in a particular specialisation is more likely to be found.

3.2.15 From this we can perhaps conclude that

- more specialised workers in the highest-skill category are more likely to be found in larger and attractive cities;
- medium-skilled workers are more likely to be found in larger cities because of the greater demand for (and training in) their specialisms;
- remote working may have some influence on the supply of specialised workers in the long term, but it is not clear that it will affect their contribution to higher productivity (except through the general effects of remote working on productivity considered in sections 3.3 and 3.4 below).

3.2.16 It therefore seems reasonable to conclude that higher specialisation of workers can be regarded as a fixed effect for any one city at any one time, irrespective of remote working and irrespective of transport or other variables within the city. Over time,

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[10] Florida, R (2005): *Cities and the creative class.* Routledge, London.

the degree of specialisation might change enough to make the city significantly more (or less) attractive in comparison with competing cities, but that is beyond the scope of the present study.

Higher productivity resulting from larger numbers of potential customers (S4)

3.2.17 The benefits of operating in a larger market include greater and more reliable demand for suppliers through access to a larger number of potential customers. Note that this is the demand-driven equivalent of S2, which is supply-driven. This is one of the classic cases of agglomeration (or "external economies of scale"): that access to a large market allows firms to become more efficient in producing products, or – through innovation supported by the larger market - to produce more specialised products which in turn allow their customers to become more efficient.

Higher productivity from amenity value of services used by staff around their workplace (S5); and

Higher productivity from indivisible facilities enjoyed by residents in general (not related to workplaces) (S6)

3.2.18 These last two effects, S5 and S6, are not in either L&T or D&P. There is scope for discussion whether the high level of amenities for staff in (for example) major city centres actually increases productivity or simply provides an externality benefit (not a free lunch, but a better choice of paid-for lunches) to staff which allows salaries to be lower than they would otherwise be (i.e. increases profits for firms, but without increasing GVA). There is some evidence from cross-city analysis[11] that residents "pay" (through lower salaries) for living in places with higher amenities. It would seem reasonable to expect this to apply at an intra-city level as well, but to pursue that requires a separate study.

Sharing effects - overview

3.2.19 Looking at the range of "sharing" micro-foundations, the only ones with obvious links to remote working are the (less conventional) "amenities for workers" ones (effect S5).

3.3 <u>Matching</u>

3.3.1 This is about labour market matching: the D&P classification identifies three different micro-foundations.

Improving quality of matches (M1); and

Improving the chances of matching (M2)

3.3.2 The underlying distinction between these is that M2 is about higher chances of recruiting an employee (and of being recruited), M1 about how good the recruit

[11] For example, Ahrend, R and A C Lembcke (2016): Does It Pay to Live in Big(ger) Cities? The Role of Agglomeration Benefits, Local Amenities, and Costs of Living. *OECD Regional Development Working Papers 2016/09*.

subsequently turns out to be for the job, and how good the job turns out to be for the person recruited.

3.3.3 For our purposes we wish also to include the labour market effects of increased qualification and specialisation, from S3.

Mitigating hold-up problems through ease of matching (M3)

3.3.4 This seems (from D&P) to be based on the suggestion that problems with employed workers are less critical if replacements are easily found. This seems to be a special case of M2, so it is not considered further.

3.4 Learning (or knowledge)

3.4.1 Again, D&P suggest three micro-foundations: knowledge generation, knowledge diffusion and knowledge accumulation.

Knowledge generation (KG)

3.4.2 We propose to assume [a] that "knowledge generation" occurs among "established" workers and is a function of interaction with similar workers in the same or other sectors, and [b] that remote workers contribute less.

Knowledge diffusion (KD)

3.4.3 We propose to assume that "knowledge diffusion" is diffusion to and among "new" workers and is a function of interaction with both "established" workers and other "new" workers, remote workers contributing less in each category. There is scope for further discussion about how much of "knowledge diffusion" takes place within firms, even small ones (especially if it is "proprietary knowledge") and how much takes place between firms -and then whether better access to training courses etc should be counted here or under "sharing" (S2).

Knowledge accumulation (KA)

3.4.4 We propose to exclude given L&T comments about lack of evidence for this.

3.5 Conclusion

3.5.1 This chapter has set out and commented on the list of micro-foundations through which agglomeration effects are thought to operate. The list is summarised in Table 3-1. The next two chapters gradually develop these ideas into specific formulae.

Table 3-1 Micro-foundations of agglomeration effects

Source: developed from D&P and L&T papers as discussed above

id	Description	Notes on treatment in this report
S1	Sharing "indivisible" facilities	Focus on goods/services provided by the facility/facilities
S2	Sharing a larger pool of suppliers	
S3	Higher productivity from greater individual worker specialisation	Not considered further : assumed to be captured in matching effects

id	Description	Notes on treatment in this report
S4	Sharing larger pools of customers/clients	
S5	Amenity value of services used by staff in particular locations	
S6	Amenity value of services/facilities used by residents in general	
M1	Labour market matching – quality of match	Considered as one effect
M2	Labour market matching – chance of matching	
M3	Mitigating hold-up problems	Not considered further
KG	Knowledge generation	
KD	Knowledge diffusion	
KA	Knowledge accumulation	Not considered further

4 REPRESENTING AND USING ACCESS TO ECONOMIC MASS

4.1 Introduction

4.1.1 As another step towards proposing formulae to model the micro-foundations of agglomeration effects, this chapter reviews the existing approach to calculating A2EM and using it in agglomeration calculations.

4.2 Non-mathematical introduction to A2EM

4.2.1 This chapter is specifically about defining A2EM effects in terms of mathematical formulae, and as such is difficult to present in non-mathematical terms. That said, Figure 4-1 provides a partly-graphic explanation of the A2EM measure, which explains the standard concept. To summarise the following sections:

- section 4.3 sets out standard calculations for A2EM and for using A2EM to calculate changes in productivity, introducing the question of how one would use separate measures of A2EM by micro-foundation in such productivity calculations
- section 4.4 considers the more specific issue of how changes in commuting trip frequency, as a result of more or less remote working, will affect the workers' overall perceptions of the connection between home-workplace;
- section **Error! Reference source not found.** considers how A2EM should treat competing modes of transport.

4.2.2 The equation-allergic reader may now wish to jump to the conclusions of this chapter, in section 4.6.

4.3 General formulae

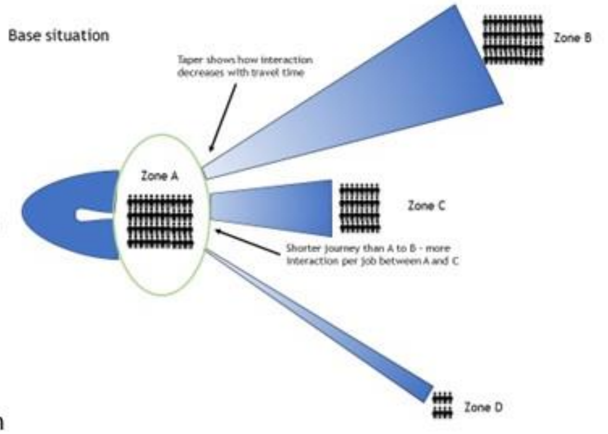
We write the typical measure of A2EM as $A_i^{f\,s} = \sum_j \left(M_j^{(f)(s)} .\ d_{ij}^{(f)(s)} \right)$ (4.1)

where

	is the measure of agglomeration for micro-foundation effect *f* for sector *s* located in zone *i*
$M_j^{(f)(s)}$	is the measure of economic mass in zone *j* relevant to micro-foundation effect *f* and to sector *s*

Figure 4-1 Calculating access to economic mass (A2EM)

The first graphic illustrates shows how the A2EM of zone A (to the left) is built up from access to its own and other zones' jobs.



The number of person symbols indicates the jobs in each zone. The tapering shapes show how the value of jobs decreases with travel time to A; their value to zone A is their width where the shaded shapes meet the green circle around zone A. So:

zone B has many jobs, but takes longer to reach - its contribution to A's A2EM is small

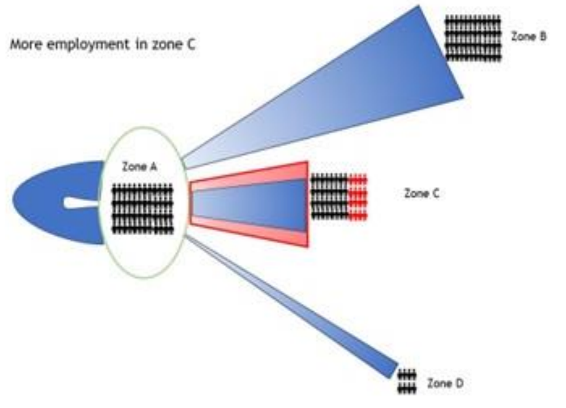
zone C has fewer jobs but can be reached more quickly - it makes a greater contribution

zone D is tiny and far away, so its contribution is hardly noticeable

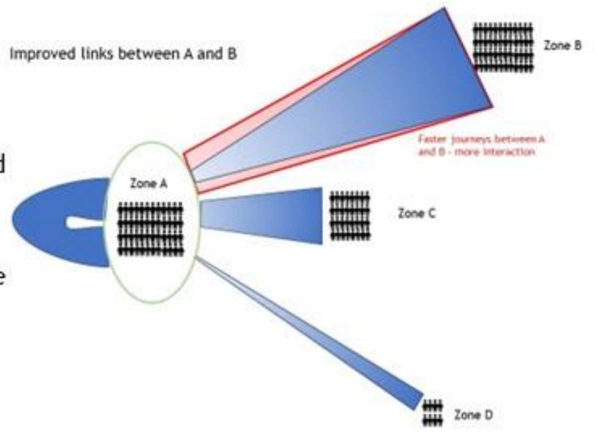
because A has many jobs, by far the largest contribution to its A2EM is its own, i.e. the value of each job in A to every other job - shown by the horseshoe shape on the left.

In practice, there are usually hundreds of zones, and A2EM has to be calculated for each of them. Small zones like D may be individually insignificant but collectively important to places like zone A

If additional jobs locate at zone C (the additional figures in red), then zone A's A2EM will increase, because the economic mass (EM) part of A2EM has increased.



If transport between A and B improves, then again zone A's A2EM will increase, because the "access to" (A2) part of A2EM has improved.



The speed or quality of travel can be measured for a single mode of travel (which will give a measure of A2EM specific to that mode) or for all modes (which will give a more general measure). But it must be consistent for all the zone pairs in the analysis.

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$d_{ij}^{(f)(s)}$	$0 \le d_{ij}^{(f)(s)} \le 1$, is the deterrence to agglomeration relevant to micro-foundation effect *f* and to sector *s* resulting from the separation between zones *i* and *j* (whether that works through generalised cost, travel time only, etc). $d_{ij}^{(f)(s)} = 1$ means there is no deterrence effect at all – everything at *j* is perfectly accessible to people or firms at *i*; $d_{ij}^{(f)(s)} = 0$ means total deterrence– anything at *j* is wholly inaccessible and unavailable to people or firms at *i*. (The deterrence function is discussed at section 4.4 below.)

4.3.1 Note that the A2EM measure A_i^{fs} can be interpreted as "the total mass in the economy being analysed, as perceived from one zone *i*, with each unit of mass discounted by the deterrent effect of having to travel to it from zone *i*". Considering the behaviour of this:

- any addition to economic mass $M_j^{(f)(s)}$ will increase A2EM for all zones *i*, but more strongly if there is little deterrence to interaction between *i* and *j* (i.e. $d_{ij}^{(f)(s)}$ is close to 1), very weakly if there is strong deterrence to interaction between *i* and *j* (i.e. $d_{ij}^{(f)(s)}$ is close to 0);
- if the deterrence function is a "weak" one i.e. $d_{ij}^{(f)(s)}$ only very slowly decreases with distance, then the A2EM measure will tend to be slightly sensitive to any transport improvements affecting travel from zone *i*; conversely
- if the deterrence function is a "strong" one i.e. $d_{ij}^{(f)(s)}$ rapidly decreases with distance, then the A2EM measure will tend to be highly sensitive to transport improvements affecting local travel close to zone *i*, and highly insensitive to improvements in longer journeys.

4.3.2 Note that if we ignore the micro-foundation effect *f* and define

$$M_j^{(s)} = E_j \tag{4.2}$$

$$d_{ij}^{(s)} = \left(g_{ij}\right)^{-\alpha^s} \tag{4.3}$$

where

E_j	is employment located in zone *j*
g_{ij}	is generalised cost between *i* and *j*

then we get back to the standard TAG A2EM formula

$$A_i^s = \left(\sum_j E_j \cdot \left(g_{ij}\right)^{-\alpha^s} \right) = \left(\sum_j \frac{E_j}{\left(g_{ij}\right)^{\alpha^s}} \right) \tag{4.4}$$

4.3.3 The TAG application of this is to calculate the relative change in GDP per worker as

$$\frac{G_i^{s(ALT)} - G_i^{s(BASE)}}{G_i^{s(BASE)}} = \left(\frac{A_i^{s(ALT)} - A_i^{s(BASE)}}{A_i^{s(BASE)}} \right)^{\beta^s} = \left(\frac{A_i^{s(ALT)}}{A_i^{s(BASE)}} \right)^{\beta^s} - 1 \qquad (4.5)$$

where

$G_i^{s(BASE)}$ is GVA per worker in sector s with workplace in zone i in the base case (and similarly ALT is the alternative case being appraised against the base)

β^s is the elasticity of productivity of sector *s* with respect to changes in agglomeration.

4.3.4 Note that this is a purely relative measure, irrespective of the size of settlement or economy considered. Doubling the population of every zone in and around London (without allowing congestion to get worse) would with this equation have the same relative effect on the productivity of every worker there as the desert island meeting of Robinson Crusoe and Man Friday had on their productivities. (Whether in fact agglomeration effects are stronger in large cities, as some evidence suggests, or uniform, or possibly stronger at both ends of the size range and weaker in the middle, is a subject for another study.)

4.3.5 There are at least two ways to modify this function to introduce the separate measures of agglomeration by micro-foundation: either by combining them into one overall measure per sector to use in equation (4.5) e.g. by defining an overall measure as

$$A_i^s = \sum_f \left(\chi^{fs} . A_i^{fs} \right) \qquad (4.6)$$

where

χ^{fs} is a weight scaling and defining the importance of micro-foundation *f* for sector *s*

or by having them operate separately i.e. with separate elasticities

$$\frac{\Delta G_i^s}{G_i^{s(BASE)}} = \prod_f \left(\frac{A_i^{fs(ALT)}}{A_i^{fs(BASE)}} \right)^{\beta^{fs}} - 1 \qquad (4.7)$$

β^{fs} is the elasticity of productivity of sector *s* with respect to changes in the measure of agglomeration specific to micro-foundation *f*.

4.3.6 We return later to the choice between these.

4.4 <u>Deterrence functions and the effect of frequency of commuting</u>

4.4.1 The standard TAG deterrence function is of the form

$$d_{ij} = \frac{1}{\left(g_{ij}\right)^{\alpha}} \qquad (4.8)$$

4.4.2 The TAG values of alpha tend to make this function highly localised, especially for consumer and business services[12]. This makes standard agglomeration calculations extremely sensitive to details of zone system specification, network representation, and the treatment of intrazonal values; it can imply implausibly high sensitivity to distance or cost in comparing short journeys The suggested alternative is a negative logistic function, i.e. (omitting the superscripts for sector *s* and micro-foundation *f*)

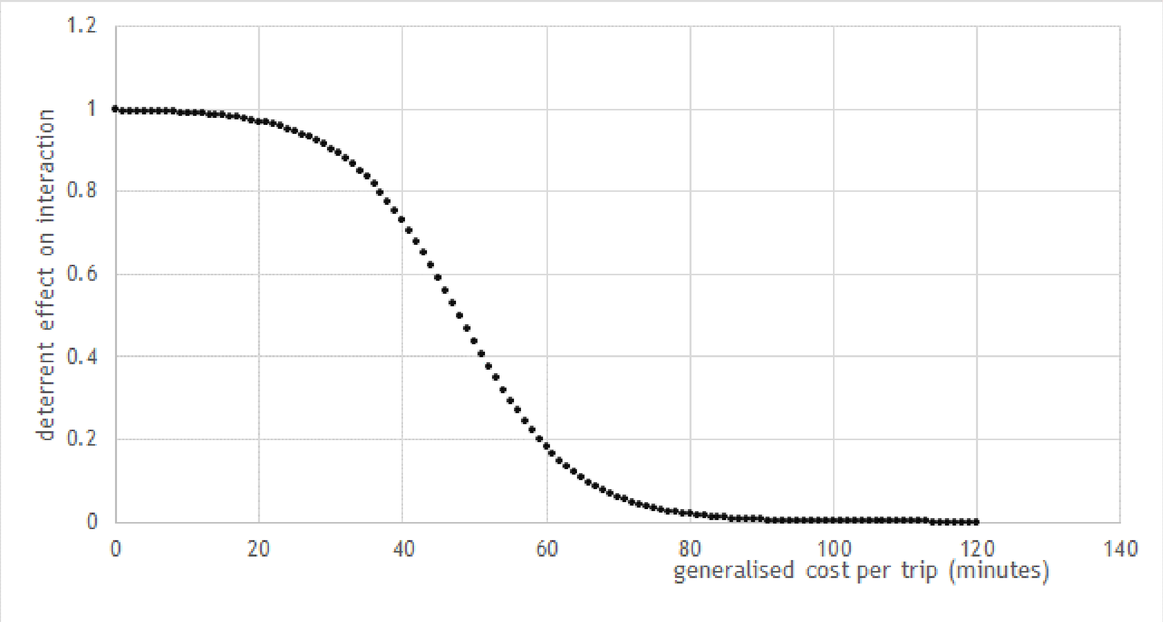
$$d_{ij} = \frac{1}{1+\exp\left(-\lambda^{D}(g_{ij}-\hat{g})\right)} \qquad (4.9)$$

where

g_{ij}	is the generalised cost of travel (or transport) per trip from *i* to *j*
$\hat{g}$	is the midpoint of the function, i.e. the generalised cost at which $d_{ij} = 0.5$
$-\lambda^{D}$	is a coefficient which defines how sharply or how gently the curve pivots about the midpoint.

4.4.3 The values of d_{ij} are plotted in Figure 4-2 for an example curve with $-\lambda^{D} = -0.125$ and $\hat{g} = 48$. A key feature of this is that it is almost flat for very short journeys, so it makes little difference whether a journey takes 5 or 10 minutes (in generalised cost), where the standard negative power function would show a large difference.

Figure 4-2 Example of the negative logistic function



4.4.4 For A2EM functions related to commuting, this needs to be extended to take account of the way in which remote working will reduce the need to travel. If we assume that the commuting cost in the deterrence function should be applied as an average cost

[12] The alpha coefficient of 1.746 for business services (TAG Unit A2.4, Table 3) implies that the contribution that one job makes to another's productivity falls by 70% each time the generalised cost between them doubles.

per working day[13], and therefore decreases as the proportion of days worked remotely increases, then the deterrence effect will change to

$$d_{ij} = \frac{1}{1+\exp\left(-\lambda^{D}\left(\left(1-r_{ij}\right).g_{ij}-\hat{g}\right)\right)} \qquad (4.10)$$

where

r_{ij} is the proportion of workers with workplace *i* and home location *j* who are working remotely, and for clarity

g_{ij} is unchanged i.e. it is still the cost of commuting *per trip*.

4.4.5 We would expect the level of remote working to be higher for long commute journeys (both through people with already-long commutes choosing to do more remote work, and people who can readily work remotely choosing more distant residential locations). r_{ij} might therefore be an increasing function of g_{ij}.

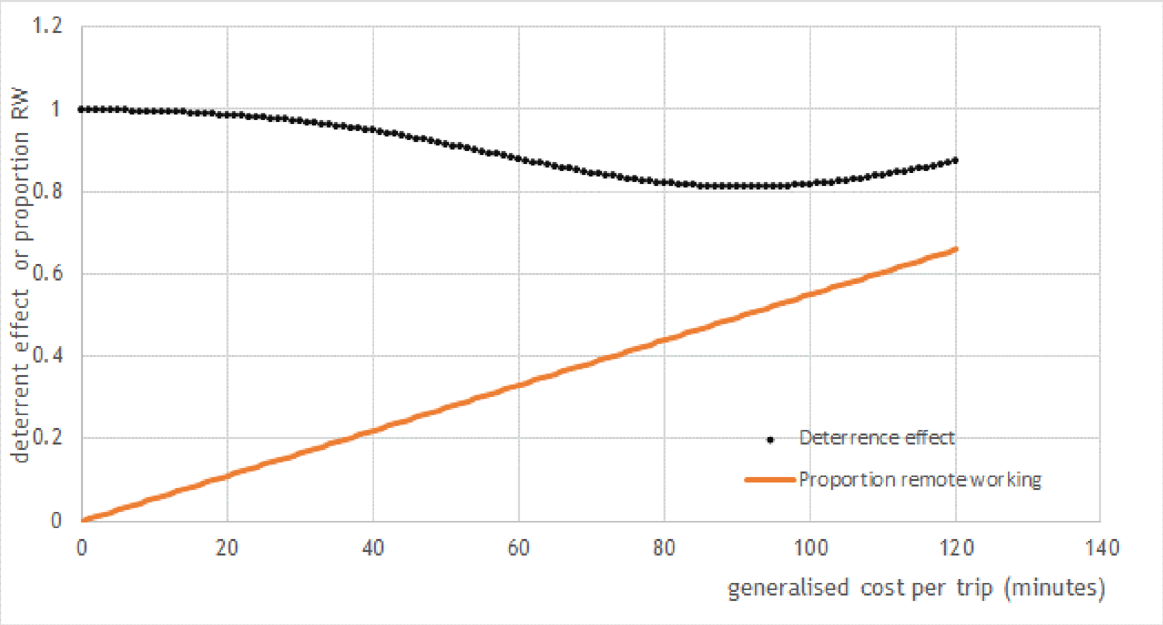
4.4.6 However, some further thought is required here, as this treatment of frequency of commuting implies that the deterrence effect falls to virtually zero if remote working reaches 100%. (The same problem would arise with the TAG power function (equation (4.3)) – it is not specific to the negative logistic formula proposed here.) Whilst we don't expect remote working to reach 100% in any sector, we should allow for it to rise to very high levels for the small minority of workers who would make their long commute journeys only very infrequently. It would be very easy to inadvertently adopt a function where the effective cost of commuting would be very low for people living very close to the workplace (even if they commuted every day), would increase as generalised cost increased (remote working going up less than proportionately) but then would decrease at higher generalised costs (remote working going up more than proportionately).

4.4.7 To illustrate this, Figure 4-3 shows the deterrence function from equation (4.10) rather than from equation (4.9), using the same coefficients as for Figure 4-2 but with the added effect that the generalised cost is effectively discounted by the proportion of remote working. The proportion of remote working is assumed to rise in a straight line from zero where generalised cost is zero to 66% (i.e. workers work remotely two days out of three) where generalised cost is 120 minutes. It can be seen that

- the minimum value of the deterrence function is quite high – at or above 0.8, compared to falling almost to zero in Figure 4-2;
- critically, the value of the deterrence function goes back towards 1 at higher generalised costs – so that in any A2EM function using this function and these coefficients, an opportunity (e.g. a potential employee or a potential job) 120 minutes away would be as valuable for productivity as one within arm's reach, and the least valuable opportunity (but still about 80% as good) would be one about 90 minutes away.

[13] This is suggested as a possibility by L&T (p36), but not discussed further.

Figure 4-3 Distance deterrence function with generalised cost discounted by an increasing proportion of remote working



4.4.8 It seems implausible that any form of remote working could result in this kind of pattern, where the value of a potential contact would first decline with increasing generalised cost and then improve with further increases in generalised cost increased further.

4.4.9 The suggested treatment for this, accepting that the reductions in commuting cost will allow some widening of the areas over which labour market agglomeration effects will work, is to apply a fixed level of remote working based on the employer's preferred level of remote working. Figure 4-4 shows the resulting deterrence effects from equation (4.10), using the same coefficients as before but with a constant value of $r_{ij} = 0.4$; the resulting curve avoids the issues that would result from that in Figure 4-3.

4.5 <u>Composite generalised cost</u>

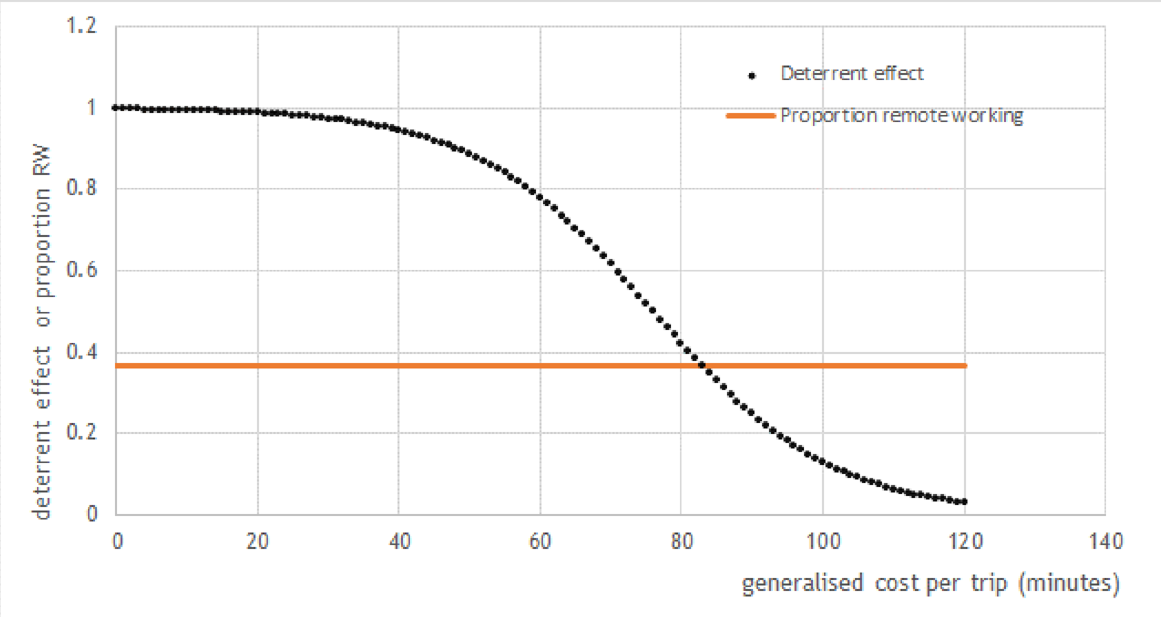
4.5.1 The suggested calculation of the composite generalised cost between *i* to *j* is a conventional logsum value, corresponding to a logit model of mode choice:

$$g_{ij} = \frac{1}{-\lambda_{ij}^{M}} \ln \sum_{m} \exp\left(-\lambda_{ij}^{M} . g_{ij}^{m}\right) \qquad (4.11)$$

where

g_{ij}^{m}	is the generalised cost of travel (or transport) from *i* to *j* by mode *m*, inclusive of any modal constant or other adjustment (e.g. higher weighting on time spent waiting or in congested vehicles)
$-\lambda_{ij}^{M}$	is a mode choice coefficient, which varies according to the zone pair *ij* being considered (e.g. varying with distance).

Figure 4-4 Distance deterrence function with generalised cost discounted by uniform 40% remote working



4.5.2 The suggested formula for the mode choice coefficient is

$$-\lambda_{ij}^{M} \quad = \quad -\lambda_{REF}^{M} \cdot \left(\frac{D_{ij}}{D_{REF}} \right)^{\gamma} \qquad (4.12)$$

where

$-\lambda_{ij}^{M}$	is the coefficient to be used in averaging generalised costs over modes, to be calculated;
$-\lambda_{REF}^{M}$	is the given value of the coefficient at reference distance D_{REF}
D_{ij}	is the distance from *i* to *j* (upper-case variable, as lower-case *d* already used for the deterrent effect of distance or travel)
γ	is a coefficient determining how $-\lambda_{ij}^{M}$ varies with D_{ij}.

4.5.3 The thinking behind this[14] is that

- in the underlying choice theory, the absolute value of $-\lambda_{ij}^{M}$ is inversely proportional to the standard deviation in the random, unmodelled (or "error") terms affecting users' preferences for each mode;
- larger values of $-\lambda_{ij}^{M}$ at short distances therefore tell the model that the standard deviation of the random terms is smaller at short distances, and low values specify that it is greater at long distances;
- that pattern of $-\lambda_{ij}^{M}$ values is achieved by the negative value of γ.

[14] Discussed further in Appendix A.

4.5.4 The logsum has a number of well-known advantages, notably that it is guaranteed to give an improvement in the composite value if any of the modes are improved[15], and it does not require trip data. It has the disadvantage that the resulting value can under some conditions turn out to be negative, which is counter-intuitive and cannot be used in the standard TAG negative power A2EM function[16]. However, this is not a problem if the negative logistic function is used (if the plot in Figure 4-2 is extended leftwards to negative values of generalised cost, the result just gets even closer to unity).

4.5.5 Note that an alternative is to use the change in logsum values and to apply this (in appropriate units) as an absolute change to a conventional trip-weighted costs. This might avoid the risk of obtaining negative generalised costs, though further analysis would be needed to confirm this.

4.6 Conclusions

4.6.1 From the above discussions we have

- a general function for measuring A2EM, which can be extended to measuring different forms of A2EM relevant to different micro-foundations;
- alternative ways of combining multiple measures of A2EM into productivity change calculations – the recommended one being the most similar to the present function;
- alternative functions to estimate the deterrent effect on economic interaction of increasing levels of generalised cost; and
- a recommended function for calculating the composite generalised cost across multiple modes.

4.6.2 This provides a toolkit which is used in the next chapter to propose different forms of A2EM applicable to different micro-foundations of agglomeration.

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15 This avoids the problem that a trip-weighted average can show a worsening if an inferior mode is improved and captures a larger share of trips (giving it a higher weight). The problem is hinted at in TAG Unit A2.4 (3.2.5, and last point in Table 6) though the standard “fix”, using the Base weights in the Alternative calculations, is no longer mentioned (and is clearly not ideal).

16 Negative results are much less likely with the distance-varying coefficient proposed. For alternatives that avoid the problem with the logsum (and address other issues of the standard logit model) see for example de la Barra, T. and Liu, L: *Discrete Choice Revisited: Attribute Correlation, Marginally Decreasing Perception of Utility and the Multiplicative Error Term*. Available at SSRN: https://ssrn.com/abstract=4394983 or http://dx.doi.org/10.2139/ssrn.4394983

5 PROPOSED FUNCTIONS BY MICRO-FOUNDATION

5.1 Introduction

5.1.1 This chapter sets out the detail of the functions that are proposed to represent the different micro-foundations of agglomeration effects. These are not based on any empirical analysis; they are intended as reasonable and plausible suggestions in order to explore the potential effects of changing levels of remote working using the hypothetical city model.

5.1.2 Sections 5.2 to 5.4 describe the proposed functions in non-mathematical terms, for sharing, matching and learning effects in turn. Sections 5.5 to 5.9 then go over the mathematical detail. 5.10 discusses a complication of the calculations as proposed.

5.2 Sharing effects

5.2.1 The following table describes the access to economic mass (or equivalent) proposed for each of the sharing effects. The mathematical specifications of these are set out in section 5.6.

Table 5-1 Suggestions for measuring the conditions for sharing effects

Micro-foundation		Proposed "access to economic mass" or equivalent term
S1	Higher productivity resulting from the availability of goods and services from indivisible facilities.	A set of "access to facility" (A2F) each measuring access to a single fixed destination (assuming the facilities in question are not only indivisible but also immobile). The "mass" of the facility may vary in response to changes in the size of or demand from the region it serves. Different A2F measures could be combined into an overall measure or used separately in productivity calculations. No remote working effect.
S2	Higher productivity resulting from a larger number of potential suppliers.	A2EM for access to the "economic mass of relevant suppliers", based for each sector, on • the mass of potential suppliers [of intermediate goods and services] by zone • whether business travel or goods movement (or a mix) is involved in delivery • the appropriate deterrence effect (very weak for many manufactured inputs).
S3	Higher productivity from individual worker specialisation permitted by a larger market for the service or skill the worker supplies.	Not modelled (see section 3.2).
S4	Higher productivity from a larger number of potential customers.	As for access to suppliers (S2 above), but reversed.
S5	Higher productivity from amenity value of services used by staff around their workplace.	A2EM in which the access is intrazonal only, and the economic mass is a weighted function of the different types of facilities particularly for lunchtime and after-work activities e.g. shops, sandwich bars, cafés, pubs, cinemas. Remote working will tend to reduce the services available. Note possible further feedback effect: if the attraction of the workplace (zone) decreases, that may

Micro-foundation		Proposed “access to economic mass” or equivalent term
		encourage further remote working as well as reducing workers’ preference for previously attractive employment centres.
S6	Higher productivity from indivisible facilities enjoyed by residents in general.	Similar to indivisibles above (S1). Not affected by remote working.

5.3 Matching effect

5.3.1 The following table describes the access to economic mass (or equivalent) proposed for labour market matching effect. The mathematical specifications of these are set out in section 5.7.

Table 5-2 Suggestions for measuring matching effects

	Micro-foundation	Proposed “access to economic mass” or equivalent term
M1	Improving quality of matches (including effects of increased qualification and specialisation, from S3)	A single measure of access to labour supply for each zone, with labour supply as the economic mass and the level of remote working affecting the effective generalised cost of commuting (i.e. the generalised cost of home-work-home travel for a worker over a month or year, given his/her proportion of remote working and commuting).
M2	Improving the chances of matching	
M3	Mitigating hold-up problems through ease of matching	

5.4 Learning effects

5.4.1 The following table describes the access to economic mass (or equivalent) proposed for each of the learning effects. The mathematical specifications of these are set out in section 5.7.4.

Table 5-3 Conditions for measuring learning effects

	Micro-foundation	Proposed “access to economic mass” or equivalent term
K1	Knowledge generation	We propose to assume [a] that “knowledge generation” occurs among “established” workers and is a function of interaction with similar workers in the same or other sectors, and [b] that remote workers contribute less.
K2	Knowledge diffusion	We propose to assume that “knowledge diffusion” is diffusion to among “new” workers and is a function of interaction with both “established” workers and other “new” workers, remote workers contributing less in each category. There is scope for further discussion about how much of “knowledge diffusion” takes place within firms, even small ones (especially if it is “proprietary knowledge”) and how much takes place between firms -and then whether better access to training courses etc should be counted here or under “sharing” (S2).
K3	Knowledge accumulation	Not considered further – see section 3.4

5.5 Functions for micro-foundations with remote working effects– preliminary

5.5.1 The following sections suggest a set of mathematical functions which can be used to explore the impacts of remote working on agglomeration through the different micro-foundations.

5.5.2 One issue mentioned earlier is that using the standard TAG formulae, the proportional effect on productivity of a doubling of A2EM is the same irrespective of the initial size of the economy modelled. In the present study it was further found that if the effects of remote working are also multiplicative, then the effects of transport changes on productivity are the same irrespective of the level of remote working assumed. (The problem is set out more precisely in the box below.) That uniformity is clearly not what is intended; therefore different mathematical forms are adopted for the mechanisms that are considered most sensitive to remote working, i.e. the matching and learning ones.

Box 5:1 Proportional calculations problem

If the extended model uses

- scaling to modify generalised cost for remote working effects through less frequent travel,
- a power function to calculate the deterrent effect of generalised cost (whether that cost is modified or no),
- multiplicative effects to adjust A2EM for other effects of remote working (people not being at their desks), and
- using a multiplicative function to calculate the productivity effects of changes in different A2EMs

then we will not see any impact of remote working in appraising agglomeration benefits of transport changes.

5.6 Sharing functions – mathematics

Indivisible facilities used by firms (micro-foundation S1)

5.6.1 The "access to mass" term for one facility will be

$$A_i^{(f=S1,n)} = m_j^{(f=S1,n)} . d_{ij}^{(f=S1,n)} \qquad (5.1)$$

where

j is the zone in which the nth facility is located

$m_j^{(f=S1,n)}$ is the measure of the scale of the nth facility. (Changes in this measure could be considered as part of the exogenous land-use change scenario.)

$d_{ij}^{(f=S1,n)}$ is the deterrent effect appropriate to this effect and to facility n of the generalised cost from i to j. The standard inverse power function of generalised cost is used.

5.6.2 If we were to consider more than one indivisible facility then each of the associated "access to mass" terms would need to be separately included in the calculation of productivity changes (see section 5.9).

Larger number of suppliers (S2)

5.6.3 Access to employment (as the only practical proxy for the number of suppliers), weighted by the importance of each sector as a supplier to the sector whose productivity is under consideration

$$A_i^{(f=S2)s} = \sum_j \left[\sum_t E_j^t . w^{(f=S2)s,t} \right] . d_{ij}^{(f=S2)(s)} \qquad (5.2)$$

(5.3)

where

s and t	are sectors, s being the one for which we are calculating A2EM;
E_j^t	is the employment in sector t at zone j;
$w^{(f=S2)s,t}$	is the importance of sector t as a supplier to sector w;
$d_{ij}^{(f=S2)(s)}$	is the deterrent effect appropriate to this effect and to sector s of the generalised cost from i to j. The standard inverse power function of generalised cost is used.

Worker qualification and specialisation (S3)

5.6.4 This is disregarded, for the reasons discussed in paragraph 3.2.9 onwards.

Larger number of customers (S4)

5.6.5 This needs to be considered in two parts – for consumer services and other industries.

Larger number of private consumers (S4A)

5.6.6 For consumer services, assumed to sell exclusively to private consumers, the relevant measure is accessibility to the population in each zone, P_j:

$$A_i^{(f=S4A)} = \sum_j P_j . d_{ij}^{(f=S4A)} \qquad (5.4)$$

where

$d_{ij}^{(f=S4A)}$	is the deterrent effect appropriate to this effect of the generalised cost from i to j. The standard inverse power function of generalised cost is used.

Larger number of commercial customers (S4B)

5.6.7 For intermediate sectors, employment is the only practical proxy for the number of customers. This needs to be weighted by the importance per worker of each sector as a customer of the sector s whose access to customers is being calculated:

$$A_i^{(f=S4B)s} \;=\; \sum_j \left[\sum_t E_j^t . w^{(f=S4B)s,t} \right] . d_{ij}^{(f=S4B)(s)} \qquad (5.5)$$

where

s and t are sectors, s being the one for which we are calculating A2EM;

E_j^t is the employment in sector t at zone j;

$w^{(f=S4)s,t}$ is the importance per worker of sector t as a customer for sector w. (Calculated, for example, as the total value of sales from sector s to sector t, divided by the total employment in sector t.)

$d_{ij}^{(f=S4B)(s)}$ is the deterrent effect appropriate to this effect and to sector s of the generalised cost from i to j. The standard inverse power function of generalised cost is used.

Amenity value of services used by staff in particular locations (S5)

5.6.8 The suggested general, assuming that the amenity values are the same for all workers irrespective of sector, is

$$A_i^{(f=S5)} \;=\; \sum_n \sum_j w^{(f=S5)n} . m_i^{(f=S5)n} . d_{ij}^{(f=S5)n} \qquad (5.6)$$

where

n is the set amenity or service types relevant to this micro-foundation S5

$w^{(f=S5)n}$ is the weight on one unit of amenity or service n

$m_i^{(f=S5)n}$ is the "mass" of amenity or service n in zone i, which may take one of several forms:

- the number of such services (e.g. the number of sandwich bars)
- the scale of an amenity e.g. the size of a public park
- a dummy value for something that is either present or absent.

$d_{ij}^{(f=S5)n}$ is the deterrent effect applicable to this function and this particular amenity. The standard inverse power function of generalised cost is used.

5.6.9 Assuming this is highly localised and we need to consider only services in the same zone (or that we have relatively large zones, as in the hypothetical city modelled later) then this simplifies to

$$A_i^{(f=S5)} \;=\; \sum_n w^{(f=S5)n} . m_i^{(f=S5)n} . d_{ii}^{(f=S5)n} \qquad (5.7)$$

5.6.10 Changes in the supply of services *n* (such as the loss of services in response to reduced demand from workers who switch to remote working) may be specified as part of the exogenous land-use scenario.

Amenity value of services/facilities used by residents in general (S6)

5.6.11 This is similar to S5 but should take account of facilities all over the city weighted (discounted) by the deterrence effect of needing to reach them:

$$A_i^{(f=S6)} = \sum_j \left(\sum_n w^{(f=S6)n} . m_i^{(f=S6)n} \right) . d_{ij}^{(f=S6)} \qquad (5.8)$$

5.6.12 The deterrent effect is taken as the standard inverse power function.

5.6.13 In the hypothetical city model used later in this report, this is used as a zonal value by workplace, implicitly assuming that the perception of these amenities is based on the workplace rather than the residential location. An alternative approach would be to calculate and use an overall value for the city as a whole; the simplest form of this would be be a population-weighted average

$$A^{(f=S6)} = \frac{\sum_i \left(A_i^{(f=S6)} . P_i \right)}{\sum_i P_i} \qquad (5.9)$$

5.6.14 These two equations could be disaggregated into values for different categories of residents. In that case the weights $w^{(f=S5)n}$, the deterrence function $d_{ij}^{(f=S6)(s)}$, and the population numbers P_i could all be distinguished by category.

5.7 <u>Matching functions – mathematics</u>

5.7.1 As in the L&T paper, we assume that matching is facilitated by the reduction in effective commuting cost associated with remote working, and not affected by remote working per se (which comes into the "learning" category below).

5.7.2 We therefore start with a straightforward measure of "access to labour mass"

$$A_i^{(f=M)s} = \left(\sum_j m_j^{(f=M)(s)} . d_{ij}^{(f=M)(s)} \right) \qquad (5.10)$$

where

$A_i^{(f=M)s}$	is the measure of agglomeration relevant to the matching effect *f=M* for sector *s* located in zone *i*
$m_j^{(f=M)(s)}$	is the relevant measure of mass, i.e. the supply of labour appropriate to sector *s*, living in zone *j*
$d_{ij}^{(f=M)(s)}$	is the deterrence to matching of the effective commuting cost between zones *i* and *j*, after taking account of the effect of remote working in sector *s* on commuting costs. The negative logistic equation is used.

5.7.3 We could also bring in the qualification/specialisation effect, which is a result of sharing processes but has the effect of improving the supply of labour:

$$A_i^{(f=M)s} = \left(\sum_j m_j^{(f=M)(s)} . q_j^{(f=M)(s)} . \ d_{ij}^{(f=M)(s)} \right) \qquad (5.11)$$

where

$q_j^{(f=M)(s)}$ is the "premium" on a worker due to the qualification or specialisation, relevant to sector *s*. (This allows for the level of qualification or specialisation to vary across zones; whether that applies or the effect is assumed to operate across the whole city is open to further discussion.)

5.7.4 This however is not pursued in the hypothetical city modelling in the present study.

5.8 Learning functions – mathematics

Knowledge generation

5.8.1 We assume that

- "knowledge generation" occurs among "established" workers and is a function of interaction with other "established" workers, across sectors
- "knowledge generation" occurs among workers working remotely but is less effective than among workers present at their workplaces;
- the knowledge generation" that occurs among remote workers is unaffected by transport or other distance-related effects;
- the relevant measure of A2EM for this micro-foundation is the sum of a component generated by remote workers and a component generated by at-workplace workers, the balance of these depending on the level of remote working in the sector considered (and potentially the level of remote working at each workplace, though that is not included in the function here).

5.8.2 The lesser effectiveness of knowledge generation spillover effects among people working remotely is described by a coefficient $\phi^{(f=KG)s}$, the ineffectiveness of remote working for knowledge generation in sector *s*, defined on a scale from 0 to 1, where 1 means a remote worker is totally ineffective (no contribution to knowledge generation) and 0 means they are just as effective as if present in person (remote working has no effect on knowledge generation).

5.8.3 The scope for knowledge generation, assuming it is occurring between firms (across sectors) and is influenced by their accessibility one to another, is then a measure of access to other established workers (in the same or other sectors) weighted by the ineffectiveness of time spent in remote working. How this works out will depend whether remote working follows a regular (effectively coordinated) timetable (e.g. everyone works in the office at least on Tuesday, Wednesday and Thursday) or patterns of remote working are random. Note that since we are talking about externalities, that means "everyone" in all offices, not just everyone in any one office.

5.8.4 If there is a common or coordinated pattern of remote working then the A2EM affecting knowledge generation can be considered as a component relating to the remote workers, unaffected by their locations[17], plus a component reflecting A2EM among workers at their workplaces, the latter including the usual transport-cost deterrence effect between workplaces. The relative ineffectiveness of remote working then means that knowledge generation effects (on agglomeration) will decrease as remote working increases:

$$A_i^{(f=KG)s} = \left(1-\phi^{(f=KG)s}\right).r^{(f=KG)*}.\left(\sum_j E_j^{(S)}\right) + \left(1-r^{(f=KG)*}\right)\left(\sum_j E_j^{(S)}.d_{ij}^{(f=KG)s}\right) \quad (5.12)$$

where

$\phi^{(f=KG)s}$	is the ineffectiveness of remote working for knowledge generation in sector *s* (and hence the expression $\left(1-\phi^{(f=KG)s}\right)$ measures the effectiveness of remote working compared to working at the workplace)
E_j^S	is the relevant "economic mass" for this micro-foundation i.e. the number of established workers employed at *j* (note upper-case superscript *S* for established[18], as distinct from lower-case superscript *s* for sector)
$r^{(f=KG)*}$	is the average level of remote working among the relevant workers
$d_{ij}^{(f=KG)(s)}$	is the deterrent effect of the generalised cost of travel between *i* and *j* for this effect and sector. (Note that this effect is not itself be affected by the level of remote working, as it only applies to interaction amongst the workers who are not remote working.) (The assumption is that all interaction among remote workers is virtual, but all interaction among in-person workers is in person.)

5.8.5 If remote working is uncoordinated, then the remote working effect has to be counted for both participants:

$$A_i^{(f=KG)s} = \left(1-\phi^{(f=KG)s}\right).\left(\sum_j r_j^{(f=KG)*}.E_j^{(S)}\right) + \left(1-r_i^{(f=KG)s}\right)\left(\sum_j E_j^{(S)}.\left(1-r_j^{(f=KG)*}\right).d_{ij}^{(f=KG)}\right) \quad (5.13)$$

where the modified terms are

[17] We assume that the services necessary to support knowledge generation among people working remotely, most obviously internet access, are available everywhere at the same standard.

[18] The superscripts *S* and *J* stem from a draft in which the categories were "senior" and "junior"

$r_i^{(f=KG)s}$	is the average level of remote working among the relevant workers in sector *s* at zone *i*
$r_j^{(f=KG)*}$	is the average level of remote working among the relevant workers at zone *j* (all sectors)
$\phi^{(f=KG)*}$	is the average ineffectiveness of remote working (over all sectors and zones).

5.8.6 The argument that this only applies to established workers will be picked up in applying this "access to mass" term, probably by making the beta coefficient vary with the proportion of established workers in the zone and sector.

Knowledge diffusion

5.8.7 We assume that "knowledge diffusion" is diffusion to and among "newer" workers and is a function of interaction with both "established" workers and other "newer" workers within each sector. The "access to mass" function is then accessibility to the weighted mix of "established" (*S*) and "new" (*J*) workers in the sector, with remote workers contributing less in each case. Again, this needs to consider whether remote working timetables are coordinated or random. For coordinated random working

$$A_i^{(f=KD)s} = \left(1-\phi^{(f=KD)s}\right).r_i^s.\sum_j\left\{\left[w^{(f=KD)Ss}.E_j^{Ss}+\left(1-w^{(f=KD)Ss}\right).E_j^{Js}\right]\right\} + \left(1-r_i^s\right).\sum_j\left\{\left[w^{(f=KD)Ss}.E_j^{Ss}+\left(1-w^{(f=KD)Ss}\right).E_j^{Js}\right]\times d_{ij}^{(f=KD)(s)}\right\} \quad (5.14)$$

$\phi^{(f=KD)}$	is the ineffectiveness of remote workers in knowledge diffusion (similar to the equivalent term for knowledge generation, above);
$w^{(f=KD)Ss}$	is the relative importance of established workers *S* as sources of knowledge diffusion in this sector *s*, and the complement of this, $\left(1-w^{(f=KD)Ss}\right)$, is the relative importance of new workers in diffusing knowledge to one another.

5.8.8 The other terms are as for knowledge generation, with the addition of superscripts S for "established" and J for "newer" workers. As in the formulae for knowledge generation, the deterrence-to-interaction term only applies to workers who are working in person, and therefore the deterrence effect itself should not be adjusted for level of remote working (unlike in the labour market matching effect). (Again, it is assumed that all knowledge-diffusing interaction by remote workers is virtual, and all that by in-person workers is in person.)

5.8.9 If uncoordinated:

$$A_i^{(f=KD)s} = \left(1-\phi^{(f=KD)}\right).r_i^{Js}.\sum_j\left\{\left[w^{(f=KD)Ss}.E_j^{Ss}+\left(1-w^{(f=KD)Ss}\right).E_j^{Js}\right]\right\} + \left(1-r_i^{Js}\right).\sum_j\left\{\left[w^{(f=KD)Ss}.E_j^{Ss}.\left(1-r_i^{Ss}\right)+\left(1-w^{(f=KD)Ss}\right).E_j^{Js}.\left(1-r_i^{Js}\right)\right].d_{ij}^{(f=KD)(s)}\right\} \quad (5.15)$$

5.8.10 Note that the equation as written allows for the proportion of remote working to vary between "established" and "new" staff. The argument that this only applies to "new" workers could be picked up in applying this "access to mass" term, for example by making the beta coefficient vary with the proportion of new workers in the zone and sector. These details have not been pursued in the hypothetical city model.

5.9 Overall function

5.9.1 The multiplicative function (from equation (4.7), paragraph 4.3.4)

$$\frac{\Delta G_i^s}{G_i^{s(BASE)}} = \prod_f\left(\frac{A_i^{fs(ALT)}}{A_i^{fs(BASE)}}\right)^{\beta^{fs}} - 1 \quad (5.16)$$

where *f* is the set of micro-foundations under consideration i.e. {*S1, S2, …, M, KG, KD*}, where in turn *S1* (at least) may itself be a set of more detailed measures.

5.9.2 An important practical consideration is that if any individual measure of A2EM, A_i^{fs}, is the same in the Base and Alternative cases, it will have no effect on the change in productivity, and can be ignored. Another (for the present purpose) is that if it is reasonable to say that "doubling the economy of the city" would result in

- doubling the standard TAG A2EM measure, and
- doubling each of the micro-foundation measures A_i^{fs},

then it is reasonable to expect that the sum of the β^{fs} coefficients will be similar to the present β^s coefficient for the sector[19]. (Note that "doubling the economy of the city" e.g. by doubling every form of economic mass in every zone, all else being held constant (so for example no increase in traffic congestion, not "doubling the size of the city" which implies a physically bigger city with longer travel distances and times, and would not necessarily double A2EM measures.)

5.9.3 A further useful property is that the calculation depends on the ratio of each Alternative A2EM value to the equivalent Base value, and isn't influenced by their absolute magnitudes; this means that that the coefficients only have to describe the sensitivity of productivity to relative change in the A2EM values for micro-foundation *f*. (Though this is of course the same property that can contribute to the problem of the whole of calculations being indifferent to the level of remote working, as discussed in section 5.5.)

[19] This assumes that the calibration used for the TAG coefficients correctly captures the combined effect of all the different micro-foundation mechanisms; and hence relies on the correlation between different effects which is a major obstacle to more detailed empirical analysis.

5.9.4 A linear combination of A2EM values (equation (4.6) feeding a single A2EM measure into equation (4.5)) would in contrast require the coefficients to scale different kinds of A2EM into a common unit as well as weighting them by relative importance. The coefficient values would then not have any intuitive meaning, nor would the sum of the values for any one sector s, and all the A2EM measures would need to be included each time the calculations were applied. For these (admittedly practical) reasons, the multiplicative form shown in equation (5.16) is preferred.

5.10 Analysing impacts by micro-effect

5.10.1 A further complication that has emerged in using the results is that the multiplicative function used to calculate the overall productivity impact effect makes it difficult to calculate the productivity change due to individual micro-foundations in a consistent way (i.e. where the changes from the individual micro-foundations sum to the overall change). The mathematics of this are shown below.

5.10.2 There doesn't seem to be a straightforward way of avoiding this problem. It is possible to correct for it, by adjusting the micro-foundation impacts so that their sum matches the overall impact, but that has a slight risk of changing the sign of an individual micro-foundation result. Since the object of tabulating the results by micro-foundation is to interpret their relative contributions to the overall result, any change of sign would be confusing; so the results by effect are presented here without such adjustment, despite the fact that they do not exactly sum to the overall impact.

Mathematics of the problem

5.10.3 The formula used to calculate the impact of the changes in A2EM resulting from a given intervention is, as discussed in PN 1,

$$\frac{\Delta G_i^s}{G_i^{s(BASE)}} = \prod_f \left(\frac{A_i^{fs(ALT)}}{A_i^{fs(BASE)}} \right)^{\beta^{fs}} - 1 \qquad (5.17)$$

$$\Delta G_i^s = G_i^{s(BASE)} . \left\{ \prod_f \left(\frac{A_i^{fs(ALT)}}{A_i^{fs(BASE)}} \right)^{\beta^{fs}} - 1 \right\} \qquad (5.18)$$

5.10.4 The obvious formula for calculating the impact of one of the micro-foundations is to take just that one change in A2EM

$$\Delta G_i^{s\{f\}} = G_i^{s(BASE)} . \left\{ \left(\frac{A_i^{fs(ALT)}}{A_i^{fs(BASE)}} \right)^{\beta^{fs}} - 1 \right\} \qquad (5.19)$$

where

$\Delta G_i^{s\{f\}}$ refers to the part of the overall change ΔG_i^s that is attributable to effect *f*.

5.10.5 If we sum these part changes over the set of different micro-foundations, it is clear that the total will not generally equal the overall change:

$$\sum_f \Delta G_i^{s\{f\}} \; = \; G_i^{s(BASE)} . \sum_f \left\{ \left(\frac{A_i^{fs(ALT)}}{A_i^{fs(BASE)}} \right)^{\beta^{fs}} - 1 \right\} \neq \; G_i^{s(BASE)} . \left\{ \prod_f \left(\frac{A_i^{fs(ALT)}}{A_i^{fs(BASE)}} \right)^{\beta^{fs}} - 1 \right\}$$

(5.20)
(5.21)

5.10.6 There does not seem to be any simple way to calculate the individual effects so that their sum will equal the product calculating the overall effect.

5.10.7 It would be possible and simple to adjust the results of equation (5.19) so as to get that equality, i.e. to ensure that

$$\sum_f \Delta G_i^{s\{f\}} \; = \; \Delta G_i^s \qquad (5.22)$$

5.10.8 However, that could in some cases have the effect of changing a small positive effect into a negative effect. As suggested above, since the object of considering the individual micro-foundations is interpretation rather than further analysis, it seems better not to risk that kind of confusion.

5.10.9 In practice, the differences between the sum of the part changes and the “correct” overall change are generally modest, and vanishingly small for many of the very small impacts calculated.

5.11 Conclusion

5.11.1 This chapter has suggested functions to measure A2EM (or variations thereon) for each of the micro-foundations of agglomeration effects that we consider relevant, and has suggested how these can be combined into the estimation of an overall productivity impact. The following chapters work towards applying these functions to a hypothetical British city.

6 THE HYPOTHETICAL CITY AND ITS MODEL

6.1 Introduction

6.1.1 This chapter describes the hypothetical city that was invented to meet the requirement for consideration of remote working to be applied to a "worked example, but not real-life", as required by the brief.

6.1.2 In implementing the city, the approach adopted was that in order to be a useful example, the city needed to be realistic, whilst not resembling any one city so closely that it could be considered to represent "real-life". It also needed to be represented by a relatively simple model with a minimum of spatial detail, which could be quickly assembled and very quickly run. It is therefore static, and does not attempt to take account of all the issues and possibilities discussed in the preceding chapters; it focusses on allowing the user to test the consequences of different definitions of A2EM as drivers of agglomeration changes. The model differs from many other hypothetical cities in economic modelling in that, amongst other things, it has explicit spatial dimensions, and is not entirely symmetrical.

6.1.3 The following sections describe

- the definition of the city itself;
- the land use pattern of the city;
- the base transport network and services; and
- the modelled levels of remote working and related inputs.

6.1.4 The model of the city is implemented in a set of Excel spreadsheets. To change the definition of the zones would require more or less a completely new model. Most other changes could be accommodated with less drastic change.

6.2 Definition of the city

Content

6.2.1 The definition consists of zone definitions, coordinates and the distances between them.

Zone definitions

6.2.2 The city and each region are represented by the zones mapped in Figure 6-1 and described, in very broad terms, in Table 6-1. Each of the residential zones is taken as representative of a significant part of the city, and includes employment mainly in local services. Note that whilst the city zones implicitly account for all of the built-up area within the city, the rural areas (suggested by the green background to the map) are simply ignored.

Figure 6-1 Zone map

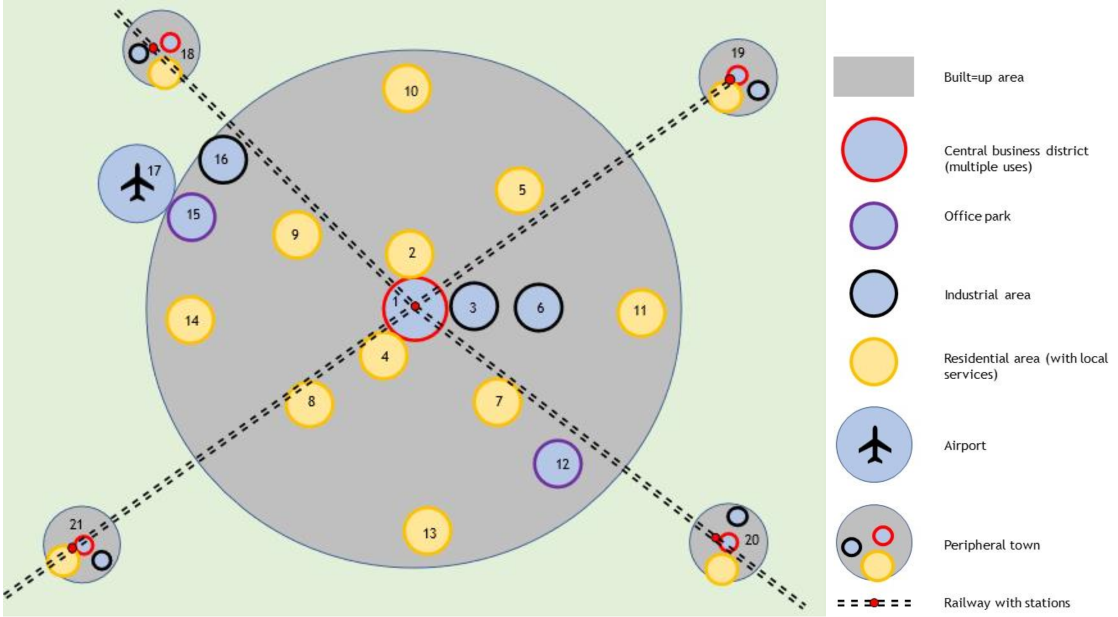

Table 6-1 Zone descriptions

Zones	Description
CBD (1)	Modern centre, predominantly offices and retail services, superimposed on historic core
Inner area (2-4)	Victorian development, high densities
Middle area (5-9)	Inter-war development, medium densities; includes one major industrial estate
Outer area (10-16)	Post-1945 development, lower densities; includes two large edge-of-city business parks and one major industrial area
Airport (17)	Medium-size regional airport; high proportion of employment in associated services rather than air transport itself
Surrounding towns (18 to 21)	Former market towns now with a significant role as dormitory towns for the city

Coordinates and distances

6.2.3 The zones have been given spatial coordinates so that the city has some realistic physical dimensions rather than existing in a dimensionless theoretical space. The coordinates are used to calculate interzonal distances; intrazonal distances are assumed (see Table 6-2). Travel distances are assumed to be slightly greater than straight-line distances.

6.2.4 By way of illustration

- the travel distance from the CBD to any one of the inner area zones is 2.2km;
- the travel distance from the CBD to the airport is 16.3km;
- the distance across the region, from town 18 to town 20, is 45.9km.

Table 6-2 Distance inputs

Input	Data	
Intrazonal distances	CBD	0.5km
	Inner zones	1.0km
	Middle zones	2.0km
	Outer zones	3.0km
	Airport	1.0km
	Surrounding towns	2.0km
Ratio travel distance: straight-line distance	1.1 (applies to all distances including intrazonals)	

6.2.5 The model also works out, from the zone coordinates, which journeys are between places on opposite sides of the CBD, and which train journeys involve changing between the two cross-city lines.

6.3 Base land-use scenario

Employment and productivity

6.3.1 The assumed base employment data is shown in Table 6-3. The sectors are those defined in the TAG agglomeration calculations. Note

- the large concentration of employment (about 28% of the total) in the CBD;
- the high proportion of consumer and producer services within the CBD jobs;
- concentrations of manufacturing jobs, and to a lesser extent construction jobs, in the three industrial zones (3, 6 and 16);
- a high proportion of airport jobs are in the "Other" sector;
- considerable numbers of jobs, especially in the Consumer Services sector, in the "residential" zones.

Table 6-3 Base employment data

Zone		Total	Manuf	Construc	ConServ	ProdServ	Other
1	CBD	**141,000**	500	500	40,000	60,000	40,000
2	Inner res N	**12,000**	500	500	5,000	3,000	3,000
3	Inner industry E	**20,500**	6,000	5,000	500	3,000	6,000
4	Inner res S	**12,000**	500	500	5,000	3,000	3,000
5	Middle res NE	**10,500**	500	500	5,000	1,500	3,000
6	Middle industry E	**20,000**	7,000	5,000	1,000	1,000	6,000
7	Middle res SE	**10,400**	400	500	5,000	1,500	3,000
8	Middle res SW	**10,400**	400	500	5,000	1,500	3,000

Zone		Total	Manuf	Construc	ConServ	ProdServ	Other
9	Middle res NW	**10,400**	400	500	5,000	1,500	3,000
10	Outer res N	**23,500**	500	500	18,000	1,500	3,000
11	Outer res E	**23,500**	500	500	18,000	1,500	3,000
12	Outer BP SE	**24,000**	1,000	500	8,000	11,500	3,000
13	Outer res S	**23,500**	500	500	18,000	1,500	3,000
14	Outer res W	**23,500**	500	500	18,000	1,500	3,000
15	Outer BP NW	**24,000**	1,000	500	8,000	11,500	3,000
16	Outer industry NW	**20,500**	8,000	5,000	500	1,000	6,000
17	Airport	**25,500**	2,000	500	6,000	2,000	15,000
18	Town NE	**16,200**	1,200	2,000	6,000	3,000	4,000
19	Town SE	**16,200**	1,200	2,000	6,000	3,000	4,000
20	Town SW	**16,200**	1,200	2,000	6,000	3,000	4,000
21	Town NW	**16,200**	1,200	2,000	6,000	3,000	4,000
Total		**500,000**	**35,000**	**30,000**	**190,000**	**120,000**	**125,000**

6.3.2 The base levels of productivity are shown in Table 6-4.

Table 6-4 GDP per worker by zone and sector

Zone		Manuf	Construc	ConServ	ProdServ	Other
1	CBD	95,040	67,761	63,330	72,654	57,000
2	Inner res N	93,639	65,028	61,077	64,552	57,000
3	Inner industry E	93,357	64,731	60,905	63,896	57,000
4	Inner res S	93,585	64,952	61,022	64,357	57,000
5	Middle res NE	93,108	64,094	60,319	61,965	57,000
6	Middle industry E	92,664	63,457	59,854	60,367	57,000
7	Middle res SE	93,085	64,064	60,299	61,894	57,000
8	Middle res SW	93,039	63,977	60,226	61,650	57,000
9	Middle res NW	93,415	64,603	60,721	63,338	57,000
10	Outer res N	93,222	64,305	60,494	62,551	57,000
11	Outer res E	93,092	64,088	60,323	61,970	57,000
12	Outer BP SE	91,985	62,381	59,018	57,609	57,000
13	Outer res S	93,062	64,040	60,286	61,843	57,000
14	Outer res W	93,151	64,178	60,391	62,204	57,000

Zone		Manuf	Construc	ConServ	ProdServ	Other
15	Outer BP NW	92,546	63,476	59,974	60,665	57,000
16	Outer industry NW	92,537	63,499	60,008	60,764	57,000
17	Airport	95,048	67,681	63,257	72,383	57,000
18	Town NE	92,793	63,610	59,954	60,718	57,000
19	Town SE	92,775	63,594	59,946	60,687	57,000
20	Town SW	92,745	63,542	59,904	60,547	57,000
21	Town NW	92,959	63,880	60,164	61,427	57,000
Average		**93,000**	**64,000**	**61,000**	**67,000**	**57,000**

Population

6.3.3 The population assumptions are shown in Table 6-5. Household numbers are not considered, but it is implied that households are larger in the outer suburbs; accordingly, the ratio of residents in work to total resident population is highest for the small number of residents in the CBD, and lowest in the outer suburbs (i.e. zones 10, 11, 13,14).

Table 6-5 Base population data

Zone		Total residents	Working residents
1	CBD	**5,000**	4,000
2	Inner res N	**60,000**	34,750
3	Inner industry E	**10**	10
4	Inner res S	**60,000**	34,750
5	Middle res NE	**75,000**	39,975
6	Middle industry E	**10**	10
7	Middle res SE	**75,000**	40,000
8	Middle res SW	**75,000**	40,000
9	Middle res NW	**75,000**	35,000
10	Outer res N	**100,000**	46,000
11	Outer res E	**100,000**	46,000
12	Outer BP SE	**10**	10
13	Outer res S	**100,000**	46,000
14	Outer res W	**100,000**	46,000
15	Outer BP NW	**10**	10
16	Outer industry NW	**10**	10

Zone		Total residents	Working residents
17	Airport	**0**	0
18	Town NE	**42,500**	21,250
19	Town SE	**42,500**	21,250
20	Town SW	**42,500**	21,250
21	Town NW	**47,450**	23,725
Total		**1,000,000**	**500,000**

Indivisible facilities and other attractions

6.3.4 For the moment, the only "indivisible facility" being considered is the airport, which is the only activity in zone 17.

6.3.5 The levels of zonal attraction for workers and for residents are defined as shown in Table 6-6.

Table 6-6 Zonal attraction data

Zone		Worker amenities	Resident amenities
1	CBD	100	100
2	Inner res N	20	20
3	Inner industry E	5	0
4	Inner res S	20	20
5	Middle res NE	10	20
6	Middle industry E	5	0
7	Middle res SE	10	20
8	Middle res SW	10	20
9	Middle res NW	10	20
10	Outer res N	10	25
11	Outer res E	25	25
12	Outer BP SE	20	0
13	Outer res S	10	25
14	Outer res W	10	25
15	Outer BP NW	20	0
16	Outer industry NW	5	0
17	Airport	20	0
18	Town NE	25	30
19	Town SE	25	30

Zone		Worker amenities	Resident amenities
20	Town SW	25	30
21	Town NW	25	30

6.4 Base transport inputs

Scope

6.4.1 This consists of separate files for walking, public transport (PT) and car inputs. The view was taken that in the absence of network detail, goods vehicle costs would be proportional to car costs and that they would have little or no impact on the results; goods transport was therefore ignored. The base public transport system consists of buses and trains.

6.4.2 Consideration was given to explicitly modelling cycling as an additional mode, or of modifying the "walk" mode into a more general "active travel" composite mode, but it was felt that this would be a distraction from the focus on remote working.

6.4.3 Differences by purpose or other market segment, and differences by time of day (e.g. PT services and overcrowding) are all potentially relevant but have been ignored in implementing the present model.

Walking

6.4.4 Walking times are taken from the distances described earlier, using a constant walking speed of 4.5km/h.

PT: Rail

6.4.5 Rail travel is assumed to be available only between the CBD and the surrounding towns, or from one of those towns to another via the CBD. Trips involving bus, car or walking to get to or from a station in another zone are not modelled.

6.4.6 There is a constant fare per km, a uniform speed and a uniform penalty for access/egress and waiting time. Through services are assumed to run from each of the four towns across the city to the opposite town (i.e. zone 18 to/from zone 20, and zone 19 to/from zone 21); journeys between the non-opposite towns are assumed to incur an interchange penalty. Values are shown in Table 6-7.

PT: Bus

6.4.7 Bus services are assumed to operate between any two zones and within each zone. There is a constant service speed, a constant fare per kilometre, and uniform penalties to represent access to/from and waiting for buses, with an additional penalty for changing buses to cross the city centre. Values are shown in Table 6-7.

Table 6-7 PT inputs

Mode	Input	Data
Rail	Rail speed	80km/h
	Rail fare	£0.30/km

Mode	Input	Data
	Rail access/waiting penalty	£2.50
	Rail interchange penalty	£2.50
Bus	Bus speed	10km/h
	Bus fare	£1.00 + £0.10/km
	Bus access/waiting penalty	£1.50
	Bus interchange penalty (cross-centre trips)	£1.20

Highway (car)

6.4.8 Car travel is assumed to have a constant speed, with a time penalty for entering, leaving or driving within the inner area (zones 1-4). The money cost is a constant rate per kilometre, with an additional charge for parking in the CBD. There is a uniform penalty (effectively an alternative-specific constant) to represent not everyone having a car (and hence, in the calculations, to avoid the results being unduly car-dominated).

Table 6-8 Car mode inputs

Input	Data
Speed	48km/h
Money cost	£0.0527/km
Inner/central area time penalty (all journeys to/from/within zones 1-4)	5 minutes
CBD parking charge	£5.00/trip arriving
Car ownership penalty (all journeys)	30 minutes

6.5 Remote working and related inputs

6.5.1 Table 6-9 shows the levels of remote working that are taken as representing the current (2023) situation. Table 6-10 shows the very low levels that are taken as representing the situation when present TAG agglomeration coefficients were estimated. Table 6-11s show the values assumed for other coefficients related to remote working effects.

6.5.2 The "current" remote working scenario generally has

- 5% remote working in manufacturing and construction (by implication, a high proportion of office/administration staff);
- 20% remote working in consumer services;
- 40% remote working in producer services.

6.5.3 Lower levels of remote working are assumed in the airport zone. The overall level of remote working (all sectors including Other) is 24% (implying that workers who can work remotely do so about half the time.

Table 6-9 Remote working levels – current

Effect	Remote working levels by sector				
	Manufacturing	Construction	Consumer services	Producer services	Other
Non-airport zones	5%	5%	20%	40%	30%
Airport zone	5%	5%	10%	20%	0%
Remote working - average	5%	5%	18%	40%	26%

6.5.4 The low remote working scenario is defined as

- 5% remote working throughout the producer services sector
- zero remote working in all other sectors.

6.5.5 This is probably comparable to the situation during the period on which the TAG model is calibrated[20]. The overall level of remote working (all sectors including Other) is 1.2%.

Table 6-10 Remote working levels – low

Effect	Remote working levels by sector				
	Manufacturing	Construction	Consumer services	Producer services	Other
Non-airport zones	0%	0%	0%	5%	0%
Airport zone				0%	
Remote working - average				4.9%	

Table 6-11 Other remote working related coefficients

Effect	Coefficient for this sector:				
	Manufacturing	Construction	Consumer services	Producer services	Other
Phi coefficient (ineffective-ness of remote training)	0.8	0.9	0.5	0.2	not defined
Proportion of established staff	80%	70%	40%	50%	not defined
Relative importance of established staff	75%	80%	50%	80%	not defined

[20] The Graham et al (2009) paper doesn't seem to say what period was covered by the data used.

7 AGGLOMERATION EFFECT COEFFICIENTS

7.1 Introduction

7.1.1 This chapter reports the coefficients used in calculating the composite generalised cost over modes and in the agglomeration calculations themselves.

7.2 Composite generalised costs over modes

7.2.1 For the journeys where there is a choice of bus or rail, the model simply takes the lower generalised cost. (In practice, wherever rail is available in the hypothetical city, the rail generalised cost is lower than that for bus.)

7.2.2 The coefficient values for the averaging over main modes (using the equations in section **Error! Reference source not found.**) are shown in Table 7-1.

Table 7-1 Generalised cost averaging coefficients

Input	Data
Reference distance for lambda coefficient (D_{REF})	15km
lambda at reference distance ($-\lambda^{M}_{REF}$)	-0.025
elasticity of lambda wrt distance (γ)	-0.8

7.3 Sensitivities for agglomeration effects

7.3.1 Table 7-2 sets out the initial thinking on the sensitivities of A2EM to cost, of productivity to A2EM changes, and of these calculation to remote working, for each of the micro-foundation effects. This thinking led to the specific coefficients reported in the following section.

Table 7-2 Initial thoughts on new elasticities

Source: own judgement

Effect	Suggestions: cost deterrence	Suggestions: sensitivity	Suggestions: effect of remote working
S1 Facilities (airport)		Probably **less** important or irrelevant for sectors which have to locate close to customers Effect of the airport (and any other transport facilities put in this category) will be weakened by virtual meetings replacing business travel – which might be assumed proportional to remote working	Not affected
S2 Suppliers	Very weak distance deterrence for manufacturing, given predominance of national or global supply changes	Probably **less** important or irrelevant for sectors which have to locate close to customers	Costs of interaction not affected by remote working

Effect	Suggestions: cost deterrence	Suggestions: sensitivity	Suggestions: effect of remote working
S4 Customers	Very weak distance deterrence for manufacturing, given predominance of national or global supply changes	Probably **more** significant for sectors which have to locate close to customers	Costs of interaction not affected by remote working
S5 Staff amenities	Cost deterrence related to residents' behaviour, not to sectors – high value as this mainly reflects lunchtime and after-work activities	More significant for sectors which depend on attracting highly mobile staff	Remote working will affect supply of commercial amenities in work zones. See also 7.3.2 below
S6 Residents' amenities	Cost deterrence related to residents' behaviour, not to sectors – low value as related mainly to leisure time activities	More significant for sectors which depend on attracting highly mobile staff (and their partners/families)	Not affected by remote working (considering non-work-related amenities of the city in general)
M Matching	Deterrence effect should be calibrated to reflect pattern of commuting, then modified by cost effects (see far right column)	More important for sectors employing highly skilled staff At least one review has suggested that labour market matching is generally the most important component of agglomeration – though not clear what evidence supports this	Effective costs of commuting reduced to some extent by remote working
KG Knowledge generation		Knowledge generation likely to be more important to highly productive sectors?	Effective costs of interactions reduced by remote working
KD Knowledge diffusion		Knowledge diffusion likely to be more important to highly productive sectors?	Effective costs of interactions reduced by remote working

7.3.2 One effect of remote working, discussed in journalism but possibly not researched, is to make the workplace and the amenities around it less important and the home and the amenities there more important. In that respect, S5 might be a weighted average of workplace and home zone amenities, weighted by the proportion of work done in each place. However, any such calculation would involve comparing the amenities enjoyed by people working at home with those enjoyed while working in a workplace, which would be difficult (and extremely varied). It does however fit with the pre-pandemic evidence that the likelihood of working at home (though not necessarily working remotely) increases with age, which is probably correlated with increasing likelihood of having a reasonably spacious home in a pleasant location, especially for those at the "empty nest" stage.

7.4 Cost deterrence and other effects

7.4.1 The current assumptions as to the coefficients in the negative power cost deterrence function are shown in Table 7-3. The coefficients for the negative logistic function used for the matching effect are shown in Table 7-4.

Table 7-3 Cost deterrence coefficients - negative power functions

Source: author's judgement.

Effect	Cost deterrence coefficient in calculating A2EM for this effect, by sector:			
	Manufacturing	Construction	Consumer services	Producer services
S1 Facilities (airport)	-0.2	n/a	n/a	-0.4
S2 Suppliers	-1.0	-1.2	-1.0	-1.8
S4 Customers	-1.0	-1.2	-2.0	-1.8
S5 Staff amenities	-2.0 (applies to all residents, not defined by sector)			
S6 Residents' amenities	-1.0 (applies to all residents, not defined by sector)			
M Matching	Uses different function – see Table 7-4			
KG Knowledge generation	-1.0	-1.2	-1.0	-1.8
KD Knowledge diffusion	-1.0	-1.2	-1.0	-1.8

Table 7-4 Coefficients for negative logistic function (matching effect)

Source: author's judgement.

Coefficient	Value (all sectors)
lambda	0.125
mid-point value	48.0

7.5 Combining effects into overall productivity impacts

7.5.1 The intention was to define the coefficients of the response to changes in A2EM so to get approximately the present TAG overall elasticities by sector and in total, whilst taking account of the thoughts about relative sensitivities of different effects described above. Given the multiplicative form of the function used, this was achieved by choosing elasticities for the new function which sum to the same value as the existing single coefficient. The following table shows the values used. For ease of reading, only non-zero values are shown.

Table 7-5 Elasticities with respect to A2EM measures by effect and sector

Source: author's judgement within overall TAG elasticities as described below. Blank means no effect.

Effect	Elasticity (beta coefficient) on A2EM for this effect, by sector:			
	Manufacturing	Construction	Consumer services	Producer services
S1 Facilities (airport)	0.003			0.005
S2 Suppliers				0.003
S4 Customers		0.018	0.018	0.005
S5 Staff amenities				0.005
S6 Residents' amenities				0.005
M Matching	0.006	0.002	0.002	0.040

Effect	Elasticity (beta coefficient) on A2EM for this effect, by sector:			
	Manufacturing	**Construction**	**Consumer services**	**Producer services**
KG Knowledge generation	0.006	0.007	0.002	0.010
KD Knowledge diffusion	0.006	0.007	0.002	0.010
Total	0.021	0.034	0.024	0.083
TAG value	*0.021*	*0.034*	*0.024*	*0.083*

7.6 Initial elasticities

7.6.1 As a check on the elasticities, TAG-type calculations (one A2EM measure per sector) were set up for the hypothetical city model as well as the more detailed calculations by micro-foundation. A test to check the elasticities were done by simulating increases in city size, implemented simply by increasing all the A2EM values by the assumed growth in the city. In the TAG-type calculation, for a small change in city size, the agglomeration calculations simply reproduce the input elasticity. For the new calculations, the elasticities were set up using the values shown in Table 7-5, which for each sector sum to the TAG elasticities. Mathematically this means that for a small change in city size, again implemented by increasing all the A2EM values, the new agglomeration calculations also reproduce the TAG elasticity; this has been tested, , confirming that the new calculations have been set up correctly.

7.6.2 It is also appropriate to consider the overall agglomeration responses. With some simple assumptions about GDP/worker, the reproduction of TAG calculations gives an overall elasticity for the four modelled sectors of just over 0.043, compared with the overall elasticity of about 0.04 for those sectors in the research on which TAG is based[21]. The new calculations give an average elasticity (weighted by employment) of just under 0.043 for the four sectors. Since the elasticities for the four individual sectors match quite precisely[22], the higher overall elasticity for the overall four-sector elasticity must be because the hypothetical city has a higher proportion of workers in the more responsive sectors, or higher productivity in those sectors, or a combination of the two.

7.6.3 It is worth noting that these initial elasticity calculations are independent of the level of remote working. This may seem counter-intuitive, when we have gone to some trouble to set up agglomeration calculations that are sensitive to remote working; but at this point we are looking at the overall response to a **given** change in the A2EM measures. This overall response is unaffected; but when we come to look at specific transport changes, or at transport changes combined with land-use changes, the resulting changes in A2EM will be different with the new calculations, and hence

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[21] Graham, D J, S Gibbons and R Martin (2009): *Transport investment and the distance decay of agglomeration benefits*. Available at https://personal.lse.ac.uk/gibbons/Papers/Agglomeration%20and%20Distance%20Decay%20Jan%202009.pdf

[22] That is, to the two significant figures in the Graham et al paper.

the productivity benefits will be different. These cases are illustrated in the following two chapters.

8 IMPACTS OF REMOTE WORKING ON AGGLOMERATION

8.1 Introduction

8.1.1 This chapter reports on the experiment carried out to test how a change in the level of remote working affects agglomeration and hence productivity. This is not strictly an essential part of the study, but it was felt to be an appropriate test on the reasonableness of the modelled consequences of remote working.

8.1.2 It is important to note that this is only about the impact of remote working on productivity **through agglomeration effects**. The more direct effects of remote working on productivity may be much greater, and potentially very negative[23].

8.2 Impacts of remote working on agglomeration effects

8.2.1 The test estimates the agglomeration impacts on productivity resulting from comparing A2EMs with "current" levels of remote working (see Table 6-9, page 53) against those with very low levels of remote working (see Table 6-10, page 53). Current remote working is thus taken as the Alternative Case, appraised against a Base Case of very low remote working.

8.2.2 Table 8-1 shows the absolute impact on GDP of each effect in each sector; Table 8-2 shows the same impacts as percentages of the Base GDP by sector and in total. Column totals are for the four sectors considered, i.e. ignoring the "other" sector. As explained in section 4, the effects by micro-foundation do not exactly sum to the overall effects; generally speaking, the larger and more diverse the impacts of the different micro-foundations on one sector, the greater the inconsistency.

8.2.3 As noted above, the levels of remote working have no direct impact on the "sharing" effects, so the results for these are all zero.

8.2.4 The model runs assumed "coordinated" remote working and therefore show results for the coordinated versions of the knowledge generation and knowledge diffusion effects (i.e. KGC and KDC, but not KGU or KDU).

Table 8-1 Increased remote working: impact on city GDP

Unit: £ million. All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.00	0.00	0.00	0.00	0.00	2.07	-4.92	-0.99	-3.84
CONST	0.00	0.00	0.00	0.00	0.00	0.45	-3.34	-0.67	-3.56
CSERV	0.00	0.00	0.00	0.00	0.00	8.95	-5.85	-4.43	-1.33
PSERV	0.00	0.00	0.00	0.00	0.00	207.95	-17.67	-30.96	159.32
ALL	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**219.42**	**-31.77**	**-37.05**	**150.59**

[23] For a short but very recent review see *The Economist*, 1 July 2023, p64, summarised in its subtitle: *Whoops! Working from home is detrimental to productivity after all.*

Table 8-2 Increased remote working: percentage impact on city GDP

All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.000%	0.000%	0.000%	0.000%	0.000%	0.064%	-0.151%	-0.030%	-0.118%
CONST	0.000%	0.000%	0.000%	0.000%	0.000%	0.023%	-0.174%	-0.035%	-0.185%
CSERV	0.000%	0.000%	0.000%	0.000%	0.000%	0.077%	-0.050%	-0.038%	-0.011%
PSERV	0.000%	0.000%	0.000%	0.000%	0.000%	2.586%	-0.220%	-0.385%	1.982%
ALL	0.000%	0.000%	0.000%	0.000%	0.000%	0.885%	-0.128%	-0.149%	0.607%

8.2.5 The results here are a combination of positive matching effects and negative knowledge effects; this is a uniform pattern for all four sectors. The positives for matching result from the effective reduction in generalised cost allowing significantly easier commuting and hence greater scope for "the best person in the best job". The negatives for knowledge effects result from the poorer performance of remote workers in both knowledge generation and knowledge diffusion.

8.2.6 Both positive and negative impacts are considerably greater for producer services than for any of the other sectors. This is partly because the change in remote working is greater for producer services (going from 5% to 40%, compared with going from 0% to 5% in manufacturing and construction or to 20% in consumer services – see Table 6-10 and Table 6-9) , and partly because producer services are much more sensitive than other sectors to changes in A2EM, and that greater sensitivity is particularly through matching and knowledge effects (see Table 7-5, page 56). At the same time, manufacturing and construction are more sensitive in terms of knowledge generation effects. The net effect is that the producer services sector gains nearly 2% in productivity through the agglomeration effects of remote working, whilst other sectors each lose a fraction of one percentage point; the overall effect on the four sectors considered is positive at about +0.6%. (The overall effect would of course be smaller again if calculated for the economy as a whole, taking account of the Other sector.)

8.3 Conclusion

8.3.1 The pattern of results, with stronger effects in producer services than in other sectors (especially in labour market matching), and positives in matching offset by negatives in knowledge generation, seems quite plausible given the growth in remote working that has been assumed, and it is therefore concluded that the results pass the "reasonableness test" mentioned at the beginning of the chapter. The results are of course entirely dependent on the coefficients chosen in the previous chapter; but it would require large changes in those coefficients or in the A2EM functions themselves – particularly to reduce the role of remote working as a facilitator of better job:worker matching – to reverse the sign on the result.

8.3.2 It needs to be kept in mind that

- these are direct effects only – so for example there is no impact on amenities for workers around their workplaces (S5), when in practice the increases in remote working among producer and consumer services workers would be expected to have a negative effect on city centre amenities and hence (on our hypothesis) a negative productivity impact;
- there is no consideration in this analysis (or indeed in present TAG agglomeration guidance) of the timescale of effects (e.g. that a reduction in knowledge generation will take time to have an impact); and
- the productivity effects here are the externality effects of remote working through agglomeration mechanisms, and exclude the direct (and potentially greater) impacts of remote working on productivity via within-firm or other internalised effects.

9 IMPACTS OF REMOTE WORKING ON AGGLOMERATION BENEFITS FROM TRANSPORT SCHEMES

9.1 Introduction

9.1.1 This chapter presents the results at the centre of the present study: the impact of remote working on the (static) agglomeration benefits of hypothetical transport proposals. This involves the comparisons of agglomeration benefit results at "low" and at "current" levels of remote working for a small set of transport changes.

9.2 The transport schemes tested

9.2.1 The transport changes considered are

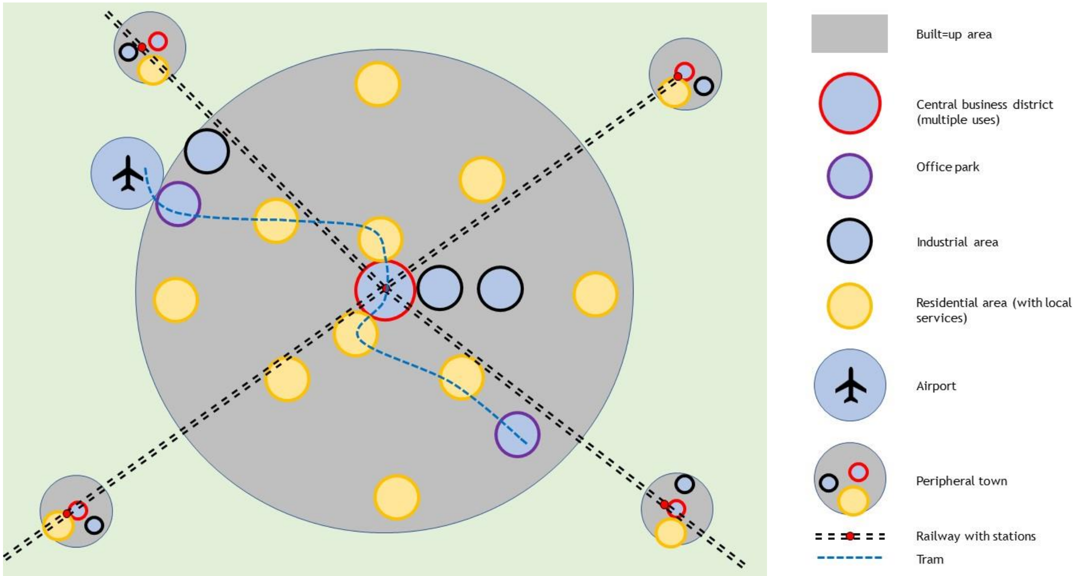
- a city tram scheme
- a workplace charging scheme
- a general improvement in all motorised transport.

Tram scheme

9.2.2 The tram line is assumed to run across the city from the airport to the major business park on the opposite side of the city, serving the other major business park, the CBD and three mainly residential zones along the way. This is illustrated in the figure below.

Figure 9-1 Hypothetical city tram scheme

For zone numbers please see Figure 6-1 (page 46)



9.2.3 The tram is modelled as a faster replacement for the bus, operating 50% faster and hence reducing the in-vehicle time component of PT generalised cost. It is assumed to be available only for journeys between the zones directly served (i.e. 1, 2, 4, 7, 9, 12, 15, 17) and does not serve intrazonal travel.

Workplace parking charge scheme

9.2.4 The workplace charging scheme is represented by a simple £5.00 charge for each car trip with destination in the CBD (zone 1). This is in addition to the CBD parking charge that is already included in the base case.

9.2.5 This intervention inevitably comes across as entirely negative in its effects, since no consideration is given to the results which might lead to the adoption of such a scheme, such as reductions in car use and consequential benefits in reduced congestion, fewer accidents and (with the present vehicle fleet) less pollution. However, it meets the underlying preference for the study experiments to include both a car-related intervention and a non-infrastructure one.

General improvement in motorised journeys

9.2.6 This intervention was added to provide an easily-implemented change in journeys between all zones, in contrast to the tram scheme which only improves travel between certain zone pairs, and the workplace parking charge which affects only travel to one particular zone. It is implemented by a 10% reduction in the total generalised cost of any PT or highway journey. The walking mode is unchanged.

9.3 TAG results

9.3.1 The two tables below show the results obtained for the hypothetical interventions from applying the present TAG static agglomeration calculations, using the logsum calculations to composite generalised costs over mode but otherwise using the published TAG formulae and coefficients.

Table 9-1 Impacts of interventions: TAG formulae

Unit: £million.

Sector	Tram	Workplace parking charge	General improvement
MANUF	0.87	-1.54	9.11
CONST	0.84	-2.02	12.32
CSERV	7.95	-8.88	53.83
PSERV	22.85	-11.17	79.95
ALL	32.51	-23.61	155.21

9.3.2 These results are included mainly for comparison (in chapter 11) with the new results below, but we note in passing that

- as would be expected, the workplace parking charge – with no offsetting benefits in terms of reduced congestion or land released for more productive development – has negative impacts on all sectors;
- in each of the three interventions, the greatest impacts arise in the producer services sector;
- the "general improvement", which improves all journeys by motorised modes, produces agglomeration benefits several times greater than either of the other interventions.

Table 9-2 Percentage impacts of interventions: TAG formulae

Sector	Tram	Workplace parking charge	General improvement
MANUF	0.027%	-0.047%	0.280%
CONST	0.044%	-0.105%	0.642%
CSERV	0.069%	-0.077%	0.464%
PSERV	0.284%	-0.139%	0.994%
ALL	**0.131%**	**-0.095%**	**0.626%**

9.4 Tram scheme results

9.4.1 The agglomeration impacts on GDP by sector and effect, and in total, are shown in Table 9-3 (absolute values) and Table 9-4 (percentages).

Table 9-3 Impacts of tram scheme: low remote working

Unit: £million. All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.03	0.00	0.00	0.00	0.00	0.29	0.23	0.06	0.61
CONST	0.00	0.00	0.36	0.00	0.00	0.03	0.14	0.03	0.56
CSERV	0.00	0.00	7.64	0.00	0.00	0.94	0.44	0.39	9.42
PSERV	1.71	1.18	1.48	0.00	1.00	21.91	2.77	3.89	33.93
ALL	1.74	1.18	9.48	0.00	1.00	23.18	3.57	4.37	44.52

Table 9-4 Percentage impacts of tram scheme: low remote working

All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.001%	0.000%	0.000%	0.000%	0.000%	0.009%	0.007%	0.002%	0.019%
CONST	0.000%	0.000%	0.019%	0.000%	0.000%	0.002%	0.007%	0.002%	0.029%
CSERV	0.000%	0.000%	0.066%	0.000%	0.000%	0.008%	0.004%	0.003%	0.081%
PSERV	0.021%	0.015%	0.018%	0.000%	0.012%	0.273%	0.034%	0.048%	0.422%
ALL	0.007%	0.005%	0.038%	0.000%	0.004%	0.093%	0.014%	0.018%	0.179%

9.4.2 As one would expect for a transport improvement with no negative consequences for generalised costs, all of the non-zero effects are positive. The majority of the gain comes from the producer service sector; in this case, because it is the most sensitive to changes in A2EM, and because it is strongly represented in the city centre and the two major business parks, all of which gain in A2EM from the tram.

9.4.3 Looking across the columns, the second-strongest is S4, the agglomeration effects of better access to customers, which are greatest for the consumer services sector. This is the major contribution to the consumer services showing the second largest gains, through in both percentage and absolute terms the impacts on that sector are much smaller than those for producer services.

9.4.4 The tram scheme has no effect on the S5 measure (workers' amenities around the workplace), because access to those amenities is assumed to be intrazonal and the tram is assumed not to carry intrazonal journeys. S6 (residents' amenities) does produce a benefit because of the improvement in interzonal journeys (particularly to the city centre); the coefficients chosen earlier determine that this only arises for the producer services sector.

9.4.5 It should be kept in mind that these results reflect positive effects in all the zones connected by the tram and zero effects everywhere else. The largest absolute gains in productivity occur in the CBD, where the per worker gain is middling but there is a very large number of jobs in the most affected sectors; the largest gains in productivity per worker are in the outer business parks (zones 12 and 15).

9.4.6 The equivalent results with the "current" levels of remote working are shown in the next two tables. Note that for clarity the base levels of productivity are assumed to remain unchanged, so both absolute and percentage differences in productivity are measured from the same starting point as for the lower levels of remote working considered above. (The alternative would be these two tables to measure differences from a "remote-working adjusted base" taking account of the effects of remote working as described in chapter 8. That does not seem helpful for present purposes; also, a properly "remote-working adjusted base" would reflect not only the agglomeration effects considered in chapter 8 but also the other, probably greater, impacts of remote working on productivity.)

Table 9-5 Impacts of tram scheme: current remote working

Unit: £million. All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.03	0.00	0.00	0.00	0.00	0.24	0.23	0.06	0.56
CONST	0.00	0.00	0.36	0.00	0.00	0.03	0.14	0.03	0.55
CSERV	0.00	0.00	7.64	0.00	0.00	0.39	0.44	0.39	8.86
PSERV	1.71	1.18	1.48	0.00	1.00	2.40	2.63	3.48	13.88
ALL	1.74	1.18	9.48	0.00	1.00	3.06	3.44	3.97	23.87

Table 9-6 Percentage impacts of tram scheme: current remote working

All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.001%	0.000%	0.000%	0.000%	0.000%	0.007%	0.007%	0.002%	0.017%

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
CONST	0.000%	0.000%	0.019%	0.000%	0.000%	0.001%	0.007%	0.002%	0.029%
CSERV	0.000%	0.000%	0.066%	0.000%	0.000%	0.003%	0.004%	0.003%	0.076%
PSERV	0.021%	0.015%	0.018%	0.000%	0.012%	0.030%	0.033%	0.043%	0.173%
ALL	0.007%	0.005%	0.038%	0.000%	0.004%	0.012%	0.014%	0.016%	0.096%

9.4.7 We are concerned with how these differ from the previous two tables; to help to identify the differences, Table 9-7 shows the "current" results (Table 9-5) as a percentage of the "low remote working" results (Table 9-3). Where both results are zero the cell is left blank.

Table 9-7 Current results as percentage of low remote working results: tram

Each value is the result from the equivalent cell in the "current" results (Table 9 3) divided by the corresponding cell in the "low remote working" results (Table 9 1). Where both are zero, the cell is blank.

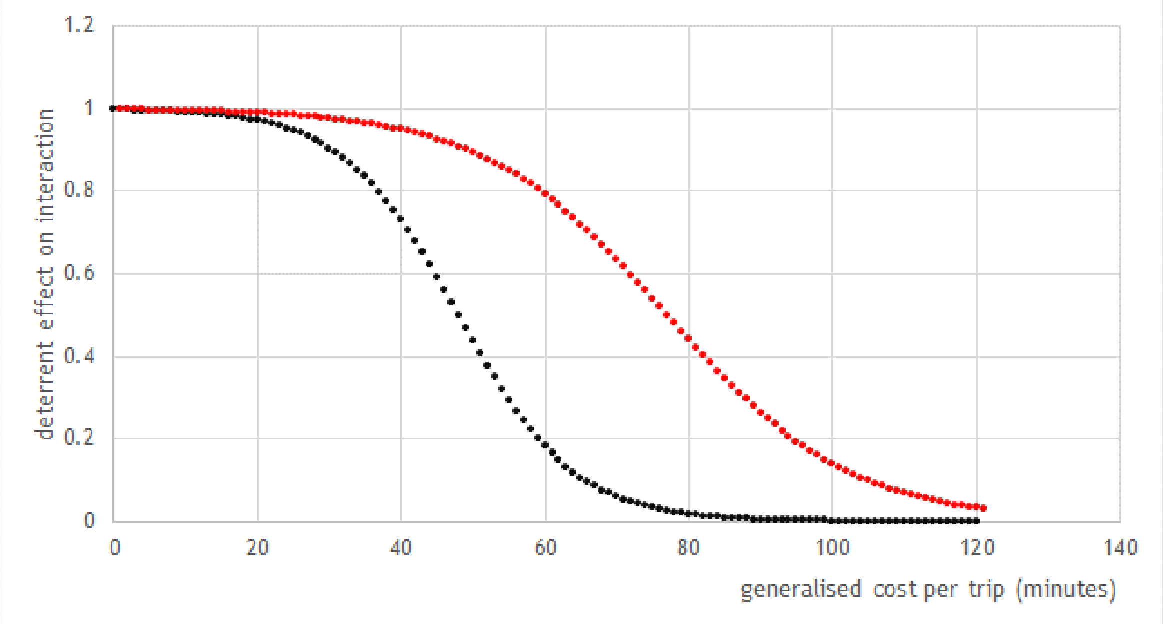
Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	100%					84%	100%	100%	92%
CONST			100%			82%	99%	100%	99%
CSERV			100%			42%	100%	100%	94%
PSERV	100%	100%	100%		100%	11%	95%	90%	41%
ALL	100%	100%	100%		100%	13%	96%	91%	54%

9.4.8 The comparison shows that

- the sharing effects are unaffected (by definition – the only one influenced by remote working is S5 (amenities at workplaces) which is not affected by the tram scheme)
- the matching effects are very significantly affected, with that for producer services being reduced to little more than 10% of the low remote working value
- knowledge effects are slightly affected, more for producer services than for other sectors and more for knowledge diffusion than for generation
- the overall effect is to reduce the benefits to little more than half of their previous values.

9.4.9 The dramatic effect on the matching effect for the producer services sector is due to the importance of the matching effect for that sector, and in particular to the properties of the negative logistic function when combined with the assumption that "perceived generalised cost" varies with the frequency of commuting. Figure 9-2 plots deterrence effect against generalised cost per trip first (black line) using the actual generalised cost per trip (as indicated on the horizontal axis), and then (red line) when the generalised cost of commuting is perceived as 37% less. The reduction reflects the average reduction in commuting frequency as a resulting of remote working in the producer service sector going from just under 5% to nearly 40%; it can be seen that the vertical position of the red line equals the vertical position of the black line at 37% lower generalised cost.

Figure 9-2 Deterrent effect of a given generalised cost per trip, zero and 40% remote working



9.4.10 In the tram scheme, there are some significant zone pairs where the generalised cost per trip is reduced from around 50 minutes (without tram) to around 40 minutes (with tram). The line of black dots in Figure 9-2 shows that in the absence of remote working, such an improvement would increase the value of one unit of economic mass from about 0.4 to about 0.7. With the reduction in perceived generalised cost due to 40% remote working, the line of red dots shows that one unit of economic mass 50 minutes away would already be worth about 0.9, and would increase only to about 0.95. This kind of effect, repeated across a number of important zone pairs, greatly reduces the overall impact of the scheme.

9.5 Workplace parking charge results

9.5.1 The results for the impacts of workplace charging under low remote working are shown in Table 9-8 and Table 9-9, and the equivalent results under approximately current remote working in Table 9-10 and Table 9-11. The current results as percentages of the low remote working results are shown in Table 9-12.

9.5.2 To avoid making the discussion any more complicated than necessary, and as we are interested here in the scale of effects, we simply ignore the negative signs in what follows.

Table 9-8 Impacts of workplace parking charge: low remote working

Unit: £million. All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.00	0.00	0.00	0.00	0.00	-0.09	-0.42	-0.02	-0.53
CONST	0.00	0.00	-0.90	0.00	0.00	-0.02	-0.35	-0.02	-1.30
CSERV	0.00	0.00	-0.11	0.00	0.00	-1.67	-0.53	-0.39	-2.69
PSERV	0.00	-0.81	-0.80	0.00	-0.41	-57.33	-1.36	-2.65	-63.34
ALL	0.00	-0.81	-1.81	0.00	-0.41	-59.11	-2.65	-3.07	-67.86

9.5.3 The general form of the results is similar to those for the tram scheme, in that all of the results are of the same sign, and a very large part of the agglomeration effect is attributable to the matching effect for the producer services sector.

Table 9-9 Percentage impacts of workplace parking charge: low remote working

All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.000%	0.000%	0.000%	0.000%	0.000%	-0.003%	-0.013%	-0.001%	-0.016%
CONST	0.000%	0.000%	-0.047%	0.000%	0.000%	-0.001%	-0.018%	-0.001%	-0.068%
CSERV	0.000%	0.000%	-0.001%	0.000%	0.000%	-0.014%	-0.005%	-0.003%	-0.023%
PSERV	0.000%	-0.010%	-0.010%	0.000%	-0.005%	-0.713%	-0.017%	-0.033%	-0.788%
ALL	0.000%	-0.003%	-0.007%	0.000%	-0.002%	-0.238%	-0.011%	-0.012%	-0.274%

Table 9-10 Impacts of workplace parking charge: current remote working

Unit: £million. All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.00	0.00	0.00	0.00	0.00	-0.09	-0.41	-0.02	-0.53
CONST	0.00	0.00	-0.90	0.00	0.00	-0.02	-0.35	-0.02	-1.29
CSERV	0.00	0.00	-0.11	0.00	0.00	-1.43	-0.53	-0.38	-2.45
PSERV	0.00	-0.81	-0.80	0.00	-0.41	-18.94	-1.25	-2.25	-24.45
ALL	0.00	-0.81	-1.81	0.00	-0.41	-20.49	-2.54	-2.67	-28.72

Table 9-11 Percentage impacts of workplace parking charge: current remote working

All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.000%	0.000%	0.000%	0.000%	0.000%	-0.003%	-0.013%	-0.001%	-0.016%
CONST	0.000%	0.000%	-0.047%	0.000%	0.000%	-0.001%	-0.018%	-0.001%	-0.067%
CSERV	0.000%	0.000%	-0.001%	0.000%	0.000%	-0.012%	-0.005%	-0.003%	-0.021%
PSERV	0.000%	-0.010%	-0.010%	0.000%	-0.005%	-0.236%	-0.016%	-0.028%	-0.304%
ALL	0.000%	-0.003%	-0.007%	0.000%	-0.002%	-0.083%	-0.010%	-0.011%	-0.116%

Table 9-12 Current results as percentage of low remote working results: workplace parking charge

Each value is the result from the equivalent cell in the “current” results divided by the corresponding cell in the “low remote working” results. Where both are zero, the cell is blank.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF						100%	100%	100%	100%
CONST			100%			100%	99%	100%	100%
CSERV			100%			86%	100%	100%	91%
PSERV		100%	100%	100%	100%	33%	92%	85%	39%
ALL		100%	100%	100%	100%	35%	96%	87%	42%

9.5.4 The pattern of changes here is very similar to that seen for the tram scheme (in Table 9-7), though the reduction in the impact of the matching effect is much less extreme, and is not reduced at all for the manufacturing and construction sectors. The changes in impact in the knowledge effects for producer services are on the other hand rather more marked (down to 92% and 85% of the low remote working benefits, compared to reduction to 95% and 90% in the tram case).

9.6 General improvement in motorised journeys

9.6.1 The results for this intervention are shown in the following five tables in the same formats as before.

9.6.2 The agglomeration impacts on productivity are larger and more varied than those for the tram and workplace charging interventions, reflecting the significant improvement for all journeys by all motorised modes. Matching is still the most important effect, and producer services still the most affected sector, but these are less dominant than in the other cases.

Table 9-13 Impacts of general improvement: low remote working

Unit: £million. All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.26	0.00	0.00	0.00	0.00	5.01	2.39	2.36	10.02
CONST	0.00	0.00	5.13	0.00	0.00	1.11	1.99	1.98	10.20
CSERV	0.00	0.00	53.22	0.00	0.00	6.83	2.65	2.72	65.42
PSERV	2.19	2.73	4.77	2.79	3.82	94.78	9.71	9.02	129.81
ALL	2.45	2.73	63.11	2.79	3.82	107.72	16.74	16.08	215.45

9.6.3 Effect S5, the productivity effect of amenities at workplaces, appears for the first time thanks to the improvement of public transport within the CBD. (The tram did not improve intrazonal journeys, and the implied share of car in the intrazonal composite generalised cost is so low that the workplace parking charge had no effect on this measure.)

Table 9-14 Percentage impacts of general improvement: low remote working

All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.008%	0.000%	0.000%	0.000%	0.000%	0.154%	0.073%	0.072%	0.308%
CONST	0.000%	0.000%	0.267%	0.000%	0.000%	0.058%	0.104%	0.103%	0.531%
CSERV	0.000%	0.000%	0.459%	0.000%	0.000%	0.059%	0.023%	0.024%	0.564%
PSERV	0.027%	0.034%	0.059%	0.035%	0.047%	1.179%	0.121%	0.112%	1.615%
ALL	0.010%	0.011%	0.254%	0.011%	0.015%	0.434%	0.067%	0.065%	0.869%

Table 9-15 Impacts of general improvement: current remote working

Unit: £million. All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.26	0.00	0.00	0.00	0.00	4.38	2.38	2.36	9.38
CONST	0.00	0.00	5.13	0.00	0.00	0.97	1.98	1.98	10.05
CSERV	0.00	0.00	53.22	0.00	0.00	3.92	2.65	2.72	62.50
PSERV	2.19	2.73	4.77	2.79	3.82	18.47	9.20	8.01	51.98
ALL	2.45	2.73	63.11	2.79	3.82	27.74	16.21	15.06	133.91

Table 9-16 Percentage impacts of general improvement: current remote working

All-sector row is for the sum of the four sectors considered. Overall effects column shows the result of the calculation taking all effects into account; individual sectors may not sum to the overall effect for reasons explained in section 5.10.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	0.008%	0.000%	0.000%	0.000%	0.000%	0.134%	0.073%	0.072%	0.288%
CONST	0.000%	0.000%	0.267%	0.000%	0.000%	0.051%	0.103%	0.103%	0.524%
CSERV	0.000%	0.000%	0.459%	0.000%	0.000%	0.034%	0.023%	0.023%	0.539%
PSERV	0.027%	0.034%	0.059%	0.035%	0.047%	0.230%	0.114%	0.100%	0.647%
ALL	0.010%	0.011%	0.254%	0.011%	0.015%	0.112%	0.065%	0.061%	0.540%

9.6.4 The effects of increasing remote working are shown in Table 9-17 below. As discussed earlier, remote working has no effect on the sharing mechanisms – amenities for workers would be affected by the closure of sandwich bars and other facilities, but that is an effect through a land-use impact rather than a direct effect of remote working. As for the other interventions, the matching and learning effects decrease by marked differently proportions, with the greatest reductions for the matching mechanisms and for the producer services sector.

Table 9-17 Current results as percentage of low remote working results: general improvement in all motorised journeys

Each value is the result from the equivalent cell in the "current" results divided by the corresponding cell in the "low remote working" results. Where both are zero, the cell is blank.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	100%					87%	100%	100%	94%
CONST			100%			88%	99%	100%	99%
CSERV			100%			57%	100%	100%	96%
PSERV	100%	100%	100%	100%	100%	19%	95%	89%	40%
ALL	100%	100%	100%	100%	100%	26%	97%	94%	62%

9.7 <u>Conclusion</u>

9.7.1 The key results in this chapter, the comparisons of agglomeration impacts at different levels of remote working, show that given the assumptions made earlier we may expect markedly different changes across the different micro-foundation mechanisms and across sectors. These are discussed further in the concluding chapter.

10 IMPACT OF REMOTE WORKING RELATED LAND-USE CHANGE

10.1 Introduction: the scenarios tested

10.1.1 This chapter considers how the agglomeration impacts of the three transport interventions considered in the previous chapter would be affected by possible land-use responses to increased remote working.

10.1.2 The land-use responses are assumed, not forecast, and are treated as alternative scenarios, not as policy interventions themselves. The agglomeration impacts have therefore been assessed separately for each scenario on the basis of the A2EM changes produced by going from the base transport situation to the alternative. The base transport situation (speeds, etc) is assumed to be the same in each scenario; the potential for the land-use changes to lead to changes in traffic congestion or in public transport services is not considered, as it would only complicate the comparisons.

10.1.3 As the land-use changes are assumed to be responses to the current increased level of remote working, their impacts are considered only in relation to the benefits at that level of working.

10.1.4 Since the focus is on the comparisons, the tables show only the percentage change in agglomeration benefits of the intervention under the changed land-use scenario relative to the benefits of the intervention under the base land-use scenario used in chapter 9. All of the tables in this chapter therefore show the percentage changes, due to the land-use change, from the relevant one of Table 9-5 (tram), Table 9-10 (workplace parking charges) or Table 9-15 (general improvement).

10.1.5 The three land-use change scenarios tested are

- reduced attraction of major business centres (scenario 2, section 10.2)
- more concentrated employment location (scenario 4, section 10.3)
- more dispersed employment location (scenario 6, section 10.4).

10.1.6 The thinking behind these is explained in each section. For each of them we consider its impact on the agglomeration benefits from each of the tram and workplace parking charge interventions.

10.2 Reduced attraction of major business centres (scenario 2)

10.2.1 This scenario considers one of the most direct land-use consequences of remote working, the likely decline in services that rely largely or partly on demand from workers close to their workplaces, e.g. sandwich bars and coffee shops, or more generally the "lunchtime and after-work economy".

Definition

10.2.2 This decline in the "lunchtime/after-work economy" is represented by

- significantly reduced attractiveness to workers;
- moderately reduced employment in the consumer service sector.

10.2.3 This was implemented as

- a 25% reduction in the “worker attraction” (see Table 6-6) of the CBD and a 50% in that attraction for each of the two major business parks (zones 12 and 15);
- 20% of the consumer service jobs in the CBD (see Table 6-3), and 50% of those in each of the two major business parks, being taken from those zones and redistributed pro rata to residential population. (Since the CBD has residents, this results in some of the jobs being reallocated there.) The net changes range from 17% reductions in employment in the business parks and 6% reduction in the CBD to 12% increases in the middle band of residential zones (zones 5, 7, 8, and 9).

Results – tram scheme with reduced attraction of major business centres

10.2.4 Table 10-1 shows the agglomeration benefits of the tram scheme under this scenario as a proportion of the benefits under the base scenario. Values of 100% mean there is no change in the benefits as a result of the change in the scenario; values greater than 100% mean increased benefits.

Table 10-1 Effect of reduced attraction of major business centres (scenario 2) on agglomeration impacts of tram

Results from the intervention tested in this scenario, as a proportion of the agglomeration impacts of the same scheme in the base (current remote working) scenario. Blank cells are those where there is no effect in either scenario.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	100%					100%	100%	100%	100%
CONST			96%			100%	100%	100%	97%
CSERV			82%			80%	91%	81%	82%
PSERV	100%	100%	99%		100%	100%	100%	100%	100%
ALL	100%	100%	85%		100%	97%	99%	98%	93%

10.2.5 The effects are largely concentrated in the consumer service sector; the productivity benefits which it would obtain from the agglomeration effects of the tram scheme are reduced by nearly 90%, with all four of the agglomeration mechanisms operating in this sector being affected.

10.2.6 Note that there are still no results for the “worker attraction” effect S5: whilst the reduction in that attraction is one of the key features of the scenario being considered, Table 10-1 is showing the comparison of two agglomeration impact calculations, one looking at the tram scheme with the original level of attractions, and the other looking at the same scheme with the reduced level of attraction (and associated employment changes). There is therefore no S5 impact in either appraisal, and nothing to compare in the S5 column.

10.2.7 Following on from that, the reductions in productivity benefit to the consumer are not the consequence of the land-use changes themselves but the consequence of the tram scheme having less effect in this scenario. The major effect at work is the redistribution of consumer service employment. The redistribution away from the major office employment locations has the effect of moving nearly 16,000 consumer service jobs (more than 8% of the total) out of zones which gain significant improvements in accessibility from the tram scheme, mostly to zones which do not gain at all from the tram.

Results – workplace charging with reduced attraction of major business centres

10.2.8 Table 10-2 shows the equivalent results from the workplace parking charge scheme, i.e. the agglomeration benefits under the scenario with reduced attraction of major business centres compared with the benefits under the base scenario. All of the benefits, by micro-foundation and in total, are negative (i.e. disbenefits) in both scenarios; the negatives cancel out in this table. Values greater than 100% therefore mean increased disbenefits in this case.

10.2.9 Note also that Table 10-2 is measuring reduction in impacts relative to those shown in Table 9-10, whereas Table 10-1 measures reduction relative to those in Table 9-5. This makes it possible that the percentages by sector in column M are the same in Table 10-2 as in Table 10-1 (100%, 100%, 80%, 100%), but the all-sector percentage is different (99% instead of 97%): consumer services, whose benefits are reduced to 80% of the original in each case, contribute less of the overall benefit in Table 10-2 than in Table 10-1, and the 20% reduction in that sector's benefit therefore has less effect on the overall change.

Table 10-2 Effect of reduced attraction of major business centres (scenario 2) on agglomeration impacts of workplace parking charge

Results from the intervention tested in this scenario, as a proportion of the agglomeration impacts of the same scheme in the base (current remote working) scenario. Blank cells are those where there is no effect in either scenario.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF						100%	100%	100%	100%
CONST			94%			100%	100%	100%	96%
CSERV			105%			80%	104%	82%	86%
PSERV		100%	96%	100%	100%	100%	100%	100%	100%
ALL		100%	96%	100%	100%	99%	101%	97%	99%

10.2.10 The effects are again largely seen in the consumer service sector, with an overall reduction in impacts, but an interesting variation in that some of the micro-foundations have a smaller impact and some have larger. The same variation is seen across sectors in the S4 column (agglomeration benefits of improved access to customers).

10.2.11 The contrasting changes in the knowledge effects for consumer services can be taken as an example of what is happening here. The impact on knowledge generation (KGC) increases by 4% (i.e. the disbenefit is slightly increased) but that on knowledge diffusion (KDC) decreases by 18% (i.e. the disbenefit is reduced).

10.2.12 The effect of the workplace parking charge is to reduce the KGC measure of A2EM for the consumer services sector by a proportion which generally increases with distance from the CBD. This spatial pattern reflects the way in which car mode is increasingly important for travel from the outer zones, including to the city centre, hence making the workplace parking charge more relevant to outer zones. This combines with a moderate deterrent effect of increasing cost which means that the CBD provides an important element of total A2EM for all the zones in the city region.

10.2.13 The changes in the KGC measure of A2EM for the consumer services sector by zone are virtually unaffected by the change of scenario. The increased disbenefit through the KGC effect is therefore entirely the result of consumer service jobs being relocated, on balance, from to zones that experience slightly larger disbenefits. This is shown in the first three data columns of Table 10-3, which show the absolute impacts on this microfoundation and sector by zone for the reduced attraction scenario (2), and for the original scenario (0), followed by the difference. It can be seen that there are greater negative absolute impacts in all non-central zones except for the two outer business parks (12 and 15). In those two zones the negative absolute impact is reduced because in scenario 2 there are fewer jobs to be negatively affected.

Table 10-3 Workplace parking charge: consumer service sector knowledge agglomeration impacts by zone

Unit: £

Zone	Zone name	Knowledge generation (KGC)			Knowledge diffusion (KDC)		
		Scenario 2	Scenario 0	difference	Scenario 2	Scenario 0	difference
1	CBD	0	0	0	0	0	0
2	Inner res N	-185	-152	-34	-121	-121	0
3	Inner ind E	-15	-15	0	-10	-12	2
4	Inner res S	-190	-155	-35	-122	-122	0
5	Middle res NE	-13962	-11103	-2859	-8155	-8199	44
6	Middle ind E	-1412	-1410	-2	-854	-1070	216
7	Middle res SE	-14117	-11225	-2892	-8139	-8116	-24
8	Middle res SW	-14383	-11436	-2947	-8172	-8219	46
9	Middle res NW	-13022	-10625	-2397	-7844	-7995	151
10	Outer res N	-70862	-65418	-5444	-41184	-48051	6867
11	Outer res E	-74776	-69031	-5744	-41743	-48738	6995
12	Outer BP SE	-16160	-32275	16115	-9164	-22901	13737
13	Outer res S	-75656	-69844	-5812	-41731	-48739	7008
14	Outer res W	-73015	-67406	-5609	-41311	-48241	6930
15	Outer BP NW	-12968	-25900	12932	-8264	-20670	12406
16	Outer ind NW	-1708	-1704	-3	-1072	-1295	223
17	Airport	-28376	-28338	-38	-16991	-21360	4369
18	Town NE	-34061	-30554	-3508	-20430	-22936	2506
19	Town SE	-34402	-30859	-3543	-20442	-22814	2372

Zone	Zone name	Knowledge generation (KGC)			Knowledge diffusion (KDC)		
		Scenario 2	Scenario 0	difference	Scenario 2	Scenario 0	difference
20	Town SW	-35078	-31465	-3612	-20827	-23378	2551
21	Town NW	-31764	-28159	-3605	-19659	-21726	2068
	Total	**-546112**	**-527073**	**-19039**	**-316236**	**-384703**	**68467**

10.2.14 In contrast, the knowledge diffusion (KDC) measure of A2EM for the consumer services sector is slightly less adversely affected by the change of scenario. This "improvement" (i.e. the reduced worsening in productivity per job) is more marked for zones further from the CBD. The effect of the redistribution of consumer service jobs is therefore generally towards zones where the disbenefit per worker is less under the new scenario. In consequence, there are positive differences (reduced loss of agglomeration) in all the zones outwith the inner and central areas, as shown in the last three data columns of Table 10-3. The two outer business parks (12 and 15) show particularly large "improvements", again (as for KGC) because there are fewer jobs there to be negatively affected.

10.2.15 The same kind of analysis can be applied to the other variations in Table 10-2

10.3 Concentrated employment (scenario 4)

Background

10.3.1 This scenario is based on the hypothesis that

- significant levels of remote working will lead to reductions in floorspace per worker (with an associated increase in "hot desking" and other changes in working arrangements)
- the resulting levels of vacancy in the office floorspace market will allow more firms to move into the CBD and other major office centres from which they were previously priced out (vacancy levels will return to "normal" levels but at lower rents than before)
- vacant office space in other locations will tend to remain vacant and eventually be converted/redeveloped to other uses

Implementation

10.3.2 This was implemented by taking 50% of producer service employment, 25% of other and 5% of both manufacturing and consumer services from the mainly residential zones in the city (i.e. all except CBD, business parks, industrial estates, airport) and approximately half those proportions from the outlying towns, and to reallocate this to the CBD and the two business parks in proportion to the base total employment.

10.3.3 The effect was to relocate just over 5% of total employment, and to increase employment in the CBD and both business parks by 14%.

Results – tram scheme with concentrated employment

10.3.4 More concentrated employment in the CBD and the two business parks (all of which are linked by the tram) has the effect of increasing some components of the agglomeration benefit but reducing others, as shown in Table 10-4.

Table 10-4 Effect of concentrated employment (scenario 4) on agglomeration impacts of tram

Results from the intervention tested in this scenario, as a proportion of the agglomeration impacts of the same scheme in the base (current remote working) scenario. Blank cells are those where there is no effect in either scenario.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	104%					104%	100%	105%	103%
CONST			108%			100%	100%	100%	105%
CSERV			107%			109%	102%	107%	107%
PSERV	108%	98%	96%		102%	111%	94%	97%	101%
ALL	108%	98%	105%		102%	110%	96%	98%	103%

10.3.5 For producer services the S2, S4 and both K effects show reduced benefits because

- the change in the land-use scenario moved more employment into already large employment zones
- for some of the agglomeration effects, the CBD's A2EM measure is dominated by access to itself
- the tram is assumed not to improve intra-zonal travel
- the change of scenario therefore moves a significant number (about 20k) of jobs into a zone where for those effects the tram produces no benefit (though some of them come from zones which the tram doesn't serve at all)

10.3.6 The benefits in S1 (productivity from the shared airport facility) goes up because the percentage improvement in productivity per worker resulting from the tram improvement is exactly the same in each tram-served zone but the proportion of employment in those zones goes up (from 51.9% to 55.5%) [calculation in L40 spreadsheet]. The same applies to S6 for producer services, and to S4 for consumer services.

10.3.7 Matching benefits go up because very little CBD labour is supplied by CBD residents so the tram is important in supplying what is now a larger labour demand.

Results – workplace charging with concentrated employment

10.3.8 More concentrated employment in the CBD and the two business parks (all of which are linked by the tram) again has mixed effects, with the negative impact of WPC generally increasing but reducing in some cases, as shown in Table 10-5.

10.3.9 Whilst the WPC applies to all car arrivals, including intrazonals, the proportion of CBD intrazonal travel by car is tiny, so the intervention has virtually no effect on within-CBD interaction.

10.3.10 The effect of the changed scenario is therefore that the negative impact of WPC is reduced for sector/effect combinations that are dominated by within-CBD interaction, whilst it increases for those where intrazonal movement is important.

10.3.11 The worsening in M effects is entirely due to a greater proportion of employment in the CBD zone.

Table 10-5 Effect of concentrated employment (scenario 4) on agglomeration impacts of workplace parking charge

Results from the intervention tested in this scenario, as a proportion of the agglomeration impacts of the same scheme in the base (current remote working) scenario. Blank cells are those where there is no effect in either scenario.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF						135%	100%	135%	107%
CONST			115%			100%	100%	100%	110%
CSERV			98%			111%	97%	108%	107%
PSERV		101%	99%	114%	88%	114%	85%	101%	110%
ALL		101%	107%	114%	88%	114%	92%	102%	110%

10.4 Dispersed employment (scenario 6)

Definition

10.4.1 This scenario assumes that a significant amount of employment relocates from major business centres into residential areas as a consequence of remote working. This counts people working at home (or possibly in other non-commuting locations such as coffee shops, parks etc) as part of the "economic mass" in A2EM calculations where the economic mass is based on numbers of workers; that is obviously open to question.

Implementation

10.4.2 40% of the producer services and Other jobs are removed from the CBD and from the two business parks.

10.4.3 These jobs are redistributed to residential areas, pro rata to working population but with a strong weighting towards outer zones/outlying towns (on the assumption that these more peripheral locations have [a] a higher proportion of larger dwellings where working at home is practical [b] a higher proportion of longer commutes such that remote working is more attractive.

10.4.4 This scenario also includes the reduction in business centre attractiveness and consumer service employment as implemented in scenario 2.

10.4.5 The net effect is that employment in the CBD and the two business parks is reduced by 35%-40%, and in residential zones is increased by up to 44%.

Results – tram scheme with dispersed employment

10.4.6 The impacts of the dispersed employment scenario on the agglomeration impacts of the tram scheme are shown in Table 10-6.

Table 10-6 Effect of dispersed employment (scenario 6) on agglomeration impacts of tram

Results from the intervention tested in this scenario, as a proportion of the agglomeration impacts of the same scheme in the base (current remote working) scenario. Blank cells are those where there is no effect in either scenario.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF	100%					100%	100%	100%	100%
CONST			79%			100%	100%	100%	87%
CSERV			82%			80%	91%	81%	82%
PSERV	72%	77%	82%		83%	67%	96%	78%	79%
ALL	72%	77%	82%		83%	72%	96%	79%	81%

10.4.7 There is no perceptible impact on manufacturing – there is too little manufacturing employment in the tram-served zones for the changes in distribution of other sectors to affect the (very small) agglomeration benefits to this sector.

10.4.8 The only impact on construction is a negative one on the S4 effect (sharing customers (the only sharing effect for construction) due to the dispersion of those customers.

10.4.9 As would be expected, there are reduced agglomeration benefits of all types for the service sectors, as the proportion of these sectors in the zones benefitting from the tram scheme is significantly reduced.

Results – workplace charging with dispersed employment

10.4.10 The impacts of the dispersed employment scenario on the agglomeration impacts of the tram scheme are shown in Table 10-7. The lack of impacts on benefits to manufacturing, and the negative one on "sharing customers" for construction, are very much the same as for the tram.

10.4.11 The dispersed employment scenario gives rise to a marked increase in the S6 "access to amenities for residents" disbenefit for the producer services sector, in contrast with it causing a decrease in the benefit for the tram scheme. Similarly dispersed employment increases the knowledge generation disbenefit of the workplace charging for both the service sectors, whereas it slightly reduces the benefits of that effect in the tram case.

Table 10-7 Effect of dispersed employment (scenario 6) on agglomeration impacts of workplace parking charge

Results from the intervention tested in this scenario, as a proportion of the agglomeration impacts of the same scheme in the base (current remote working) scenario. Blank cells are those where there is no effect in either scenario.

Sector	S1	S2	S4	S5	S6	M	KGC	KDC	Overall effect
MANUF						100%	100%	100%	100%
CONST			65%			100%	100%	100%	76%
CSERV			105%			80%	104%	82%	86%
PSERV		84%	95%	62%	144%	62%	154%	85%	72%
ALL		84%	81%	62%	144%	63%	127%	85%	74%

10.4.12 The overall effect is to reduce the (negative) impacts of the scheme because jobs have moved away from the zone most (adversely) affected.

10.5 Conclusions on changed land-use scenarios

10.5.1 Two of the scenarios considered, those in which increased remote working leads to

- loss of "lunchtime and after-work" services in major business centres (scenario 2), and to
- dispersion of employment towards residential areas (with the same loss of services for workers) (scenario 6).

result, unsurprisingly, in reduced agglomeration benefits from transport improvement (or reduced malefits from an intervention which reduces agglomeration), though the levels of change differ across effects and across sectors.

10.5.2 The scenario in which employment concentrates in major business centres (scenario 4) has a marginally positive effect on the agglomeration benefits of the tram scheme, whilst slightly increasing the net malefit of the WPC scheme:

- the negative consequence with WPC is fairly simply due to putting more jobs in the one location which is disadvantaged by the intervention;
- the small scale of positive consequences for tram stems from the mix of positive and negative impacts by micro-effect and sector. Some of the agglomeration effects in the CBD are dominated by intra-zonal A2EM; more employment in the CBD increases this domination, but the intra-zonal A2EM is not improved by the tram so the benefit is reduced.

10.5.3 It is important to keep in mind that this analysis looks at the impact of the changed land-use disposition only on the agglomeration benefits of the hypothetical schemes. The concentration of activity in scenario 4 might well produce significant agglomeration benefits in itself (i.e. by redistributing the economic mass rather than changing access to it); the dispersion scenario (6) might well do the opposite.

11 CONCLUSIONS

11.1 Introduction

11.1.1 This report argues that consideration of how remote working may affect agglomeration effects and benefits requires the measurement of "agglomeration" to be broken down from a single effect per sector as defined in TAG into distinct "micro-foundations" or "micro-effects", because of the different ways in which remote working may impact upon these.

11.1.2 Drawing on the existing literature, these "micro-foundations" can be grouped into

- sharing effects
- matching effects
- learning (knowledge) effects.

11.1.3 Our review of these effects indicates that different effects relate to different aspects of the transport system. Most obviously, labour market matching (i.e. which worker fills which job) depends on passenger transport for commuting, whilst "sharing" a wider source of suppliers of standard commodities or manufactured goods will depends largely or entirely on appropriate freight transport.

11.1.4 It follows that some micro-effects – those that depend largely or entirely on freight transport – will be unaffected by remote working (at least so long as the firms involved manage any possibilities of remote working so that goods can be produced, delivered and used as efficiently as before). In contrast, labour market matching, which has traditionally been about "who commutes to which job", is very directly affected by remote working, though the consequences are not simple or self-evident. Some of the other micro-effects are more complex again.

11.1.5 A small but non-trivial numerical model of a hypothetical British city has been set up to test the consequences of these suggestions. This uses different measures of access to economic mass (A2EM) for different micro-effects, and different sensitivities to change in A2EM for each sector; the A2EM specifications and the sensitivities to them are themselves all hypothetical, though consistent with existing evidence on overall sensitivities.

11.1.6 Some initial experiments were carried out with this model to look at the impacts of remote working itself on agglomeration effects. (It is important to note that these experiments only consider the productivity impacts of remote working through agglomeration, i.e. through externality effects; they do **not** take account of the internal effects whereby remote working within one firm may be good or bad for the productivity of that firm itself.) These experiments suggest that increases in remote working will have positive effects on matching effects but negative effects on knowledge-related effects. The balance in the experiments is positive for the producer service sector, slightly negative for manufacturing and construction, and as a result slightly positive overall. The difference between sectors arises from the greater importance of job:worker matching assumed for the producer services sector, and the degree to which that matching is improved through remote working reducing the perceived disutility of commuting. The risk that increased remote working will have negative impacts on knowledge generation and diffusion, and hence a negative impact on long-term growth in productivity, is clearly a policy concern (which others have expressed in these or other terms) which may need to be set against the potential congestion-relieving benefits of increased remote working. (Other environmental impacts of remote working, from domestic and office energy use, should also be noted – see for example recent work in Scotland[24].)

11.1.7 The main focus of the research is on how increasing levels of remote working will affect the agglomeration benefits arising from different types of transport schemes. Experiments with the numerical model of the hypothetical city indicate that increased levels of remote working will generally tend to reduce the benefits of transport improvements, though to different degrees for different types of schemes. The experiments also suggest that the reductions may change if land-use distributions respond significantly to remote working; the directions of change will depend on the form that the land-use responses take.

11.1.8 The focus of the numerical experiments was on movement within a large city (of the order of one million inhabitants). Inter-city agglomeration effects would be more strongly related to changes in business travel. Whilst "remote meetings" are logically distinct from "remote working", there is clearly a linkage between them, and some of the comments below reflect the likely impact of increases in "remote meeting" even though that was not formally a subject of the study.

11.2 Conclusions – short-term TAG adjustments

11.2.1 This section sets out suggestions as to possible sensitivity tests to be applied to existing TAG calculations to take account of the possible impacts of remote working on agglomeration effects. To arrive at these suggestions, the discussion below considers first the effect of changing the way that agglomeration benefits are calculated (from standard TAG to the method used in the project) and then at the effects of increased remote working. The suggestions have to take into account both of these.

Findings to date

11.2.2 The three tables below show in turn different agglomeration results from testing the tram scheme, the WPC proposal and a general 10% generalised cost reduction for all highway and PT journeys. Each table shows the impacts as the percentage in GDP by sector and for the total of the four sectors considered, for three different versions of the agglomeration benefit calculations:

- using the present TAG decay formulae and elasticities;
- using the new calculations described in this report, at very low levels of remote working; and
- using the new calculations, at "current" levels of remote working.

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[24] Reported as Riley, R, A Duffy, S Foster, M Bosredon and D Simmonds (2021): *Emissions impact of home working in Scotland*. Report by Element Energy to ClimateXchange Scotland. Available at https://www.climatexchange.org.uk/research/publications-library. Summarised in M Bosredon, D Simmonds (2022): *Is homeworking good for the environment in Scotland?* Proceedings of the STAR Conference, Glasgow, available at /https://starconference.org.uk/star/2022/bosredon.pdf

Table 11-1 Tram test results (% change in GDP): alternative calculations

Source: own calculations as described earlier. Note that "impact under TAG" is calculated using TAG decay coefficients and elasticities but applied to the same logsum generalised costs as in the new calculations.

Sector	Impact under TAG	Impact under new calculation (low RW)	Impact under new calculation (current RW)
MANUF	0.027%	0.019%	0.017%
CONST	0.044%	0.029%	0.029%
CSERV	0.069%	0.081%	0.076%
PSERV	0.284%	0.422%	0.173%
Total (4 sectors)	**0.131%**	**0.179%**	**0.096%**

Table 11-2 WPC test results (% change in GDP): alternative calculations

Source and note as for Table 11-1.

Sector	Impact under TAG	Impact under new calculation (low RW)	Impact under new calculation (current RW)
MANUF	-0.047%	-0.016%	-0.016%
CONST	-0.105%	-0.068%	-0.067%
CSERV	-0.077%	-0.023%	-0.021%
PSERV	-0.139%	-0.788%	-0.304%
Total (4 sectors)	**-0.095%**	**-0.274%**	**-0.116%**

Table 11-3 General cost reduction results (% change in GDP): alternative calculations

Source and note as for Table 11-1. This test assumes a 10% reduction in the overall generalised cost of any journey by car or PT. There is no change in generalised cost of walking.

Sector	Impact under TAG	Impact under new calculation (low RW)	Impact under new calculation (current RW)
MANUF	0.280%	0.308%	0.288%
CONST	0.642%	0.531%	0.524%
CSERV	0.464%	0.564%	0.539%
PSERV	0.994%	1.615%	0.647%
Total (4 sectors)	**0.626%**	**0.869%**	**0.540%**

11.2.3 The following points can be noted. (To avoid making the discussion any more complicated than necessary, and as we are interested here in the scale of effects, we simply ignore the negative signs in Table 11-2.)

11.2.4 Looking at the first and second columns of percentages, the overall impacts using new calculations with low remote working are greater than the impact under the TAG calculations in all three cases[25]. There are however

- marked differences in the scale of change: a near trebling of the WPC results but only about 40% increases in the other two cases;
- differences in the direction of change among sectors, which themselves generally differ across the three cases. Only the producer services sector consistently shows a larger impact under the new calculations in all three cases.

11.2.5 Looking at the second and third columns, there is a consistent reduction in the scale of impacts as a result of going from very low to current levels of remote working. There are however marked differences in the scale of change, both across the three cases and between the four sectors; again, the producer services sector can be seen as showing the largest reductions in each case.

11.2.6 The variations in impact observed are due to the interaction between the specifics of the scheme being tested and the new details of the calculations. These are discussed in more detail in Appendix B. More specifically, the variations are attributable to the way that

- "sharing" effects which could in some circumstances be important to manufacturing and construction are weak or non-existent in the urban passenger context considered here;
- most importantly, the definition of the labour market "matching" effect is more sensitive to improvements in home-to-job (rather than job-to-job) accessibility, is particularly important to the producer services sector which is especially significant in the zones served by the tram scheme; and the negative logistic function chosen for the matching effect is particularly sensitive at the range of generalised costs where the tram makes significant improvement. This was discussed earlier (see section 9.4, particularly around Figure 9-2).

11.2.7 In more general terms, the effect of remote working in the deterrence function used for the matching function, and in this particular scheme, is to move a high proportion of urban journeys onto the parts of the red curve where improvements have much less impact on A2EM. Conversely, looking at the right-hand end of Figure 9-2, remote working means that improvements from say 90 minutes per trip to 80 minutes per trip will make a greater absolute contribution to increasing A2EM. Putting this in less formal terms again,

- for journeys that are already at a reasonable daily commuting range, the effect of increased remote working will be to reduce the agglomeration benefits of transport improvement;

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[25] Note the contrast with the initial elasticities considered in section 7.6, which confirmed that (by design) the overall effect of a given small change in A2EM was the same in the new calculations as in TAG. The difference is that here we are picking up the changes in the calculations of A2EM, i.e. the A2EM changes for given transport supply changes are not the same as in TAG.

- for journeys that are at or beyond the upper limit of the daily commuting range, remote working will increase the agglomeration benefits of improvement.

11.2.8 The exact results are clearly dependent on the particular coefficients chosen for the negative logistic function. It will be remembered that this function was introduced into the matching effect specifically because the negative power function (in present TAG) gave no response to remote working levels at all.

11.2.9 Any conclusions therefore have to be qualified by noting the need both

- for further research into the appropriateness of the negative logistic function, or alternatives, and into the calibration of the chosen function; and
- for further consideration of how remote working modifies the resulting deterrent effects (bearing in mind the different ways in which remote working may operate – as a benefit to the employee, as a cost-reducing measure for the firm, etc).

11.2.10 To consider how the expected impacts under the new calculations and at current levels of remote working compare with present TAG results, we have to go back to the three tables above and compare the third column of percentages with the first. The picture is unclear. In the tram and general improvement cases, the agglomeration impacts are slightly reduced; in the WPC case they are increased. There is clearly not much basis here for a general conclusion (even disregarding the highly hypothetical nature of the model and its coefficients); but in so far as “real” schemes are typically network improvements rather than changes to the generalised cost of arriving in one particular zone, “real” schemes are probably likely to be more like the tram and general improvement cases, and hence if anything the agglomeration benefits are likely to be decreases.

11.2.11 A possible sensitivity test for remote working effects would therefore be as follows:

- for schemes focussed (or which pre-pandemic would have been seen as focussed) on commuter travel to major office centres, to reduce the standard TAG agglomeration benefit for producer services in proportion to the expected level of remote working (with no change to the results for the other sectors);
- for other urban schemes, to make a smaller reduction;
- for schemes with a significant element of improvement for long-distance commuting, to consider the possibility that the agglomeration impact will be increased.

11.2.12 The first of these is expanded in the box below. These suggestions need to be treated with caution given the wide range of uncertainties involved and the limited evidence from even the hypothetical city as well as the wide range of schemes that have to be appraised.

Box 11:1 Suggested adjustment – commuter-focussed schemes

<table>
<tr><td colspan="2">Suggested adjustment (pending further research) to TAG static agglomeration benefits for schemes where
a major source of benefits is improvement in commuter travel into a major office centre or centres;
the existing agglomeration benefits accrue mainly to the producer service sector.</td></tr>
<tr><td>Step 1</td><td>Calculate agglomeration benefits by sector for each forecast year, in present conventional way</td></tr>
<tr><td>Step 2</td><td>Forecast the level of remote working in the producer services sector in each forecast year on the definition used in this report i.e. the percentage of days worked at home by workers who could commute to an out-of-home workplace</td></tr>
<tr><td>Step 3</td><td>Scale down the agglomeration benefits to the producer services sector by that percentage for each forecast year, i.e. if 40% of days are forecast to be worked remotely, reduce the benefits by 40%. The greater the level of remote working forecast, the more the benefit will be reduced.</td></tr>
</table>

11.3 Conclusions – further research

11.3.1 Potential further research can conceptually be split into two broad areas:

- first, testing, revising, measuring and understanding the different micro-effects of agglomeration;
- secondly, researching and understanding how those micro-effects are affected by remote working.

11.3.2 Practically, of course, these are inseparable, in that we believe remote working is now having significant effects on the micro-foundation processes.

11.3.3 Further research into the micro-foundations does not of course have to take the present list (Duranton and Puga, extended by the present author) as given. For example: the present classification arguably counts the productivity benefits of staff training and development under "knowledge diffusion", leaving the "matching" effect counting only the intrinsic suitability of the worker for the job and vice versa, perhaps only at the time of appointment; it is not clear that such a separation is entirely helpful.

11.3.4 Such research should also take account of the impacts of "remote meeting" between employees of different firms, though ideally those should be distinguished from the impacts of remote working.

11.3.5 We would suggest that such research should also look towards the potential future impacts of further automation, which might allow forms of remote working in occupations and sectors where it is so far impossible.

11.3.6 The above suggestions assume, like the research reported here, that remote working levels are exogenous. That means that a requirement for using the results of any such research will be to have exogenous forecasts of future levels of remote working (and remote meeting). A more comprehensive approach to understanding future change (though not necessarily a convenient one for transport appraisal) might be to develop more of an equilibrium model, in which levels of remote working are endogenous and adjust to some kind of optimum[26].

11.3.7 A key issue is how the disutility of commuting from a given residential zone to a given workplace varies with the possibility of remote working. As discussed much earlier in this report, remote working may take different forms:

- it may be treated purely as a way for the firm to improve its employees' terms and conditions, with workers being largely or entirely free to choose whether to work at home or in the office, according to their personal preferences and circumstances;
- it may at the other extreme be treated as a cost-reduction measure for the firm, with a significant reduction in office floorspace and a rota system for remote working to ensure that a matching proportion of staff work at home each day;
- it may be treated as a means of "getting different types of work done in the best places", i.e. with workers required to come into the office for meetings and other interactive activities, but encouraged to work wherever they find they are most productive when carrying out solo tasks such as writing up the conclusions of reports. (In this case, desk space for working "alone" will be available but may be limited, as more space is taken up by meeting rooms and other spaces for interaction between workers.)

11.3.8 The fact that levels of commuting seem to have fallen significantly more on Fridays, and to a lesser extent on Mondays, suggests that to date some mix of the first and last of these is predominant. If that remains the case, then over time, competition for labour may tend to limit take-up of the second option, which would be markedly less attractive for most workers. These changes, and the evidence of some increases in travel at the weekends, obviously raise a whole range of issues for transport modelling and appraisal, and in particular for public transport operators.

11.3.9 A further and critical issue relating to remote working and labour market matching is how to represent the reduction in effective generalised cost of home-work-home travel that results from a reduced frequency of commuting. The core of the problem here is that if there is the option for people to work wholly remotely, then their effective generalised cost apparently drops to zero, and the whole national (or greater) labour market becomes perfectly accessible. This could dominate "access to labour" calculations and render the nearer labour supply, and any transport improvements, irrelevant to this particular micro-effect. That does not seem intuitively correct, but a better solution is not obvious. There are also the issues around the shape of the deterrence curve with respect to effective generalised cost, including the very high sensitivity of the conventional inverse power function, and the problem of all results being in equal proportion (see section 5.5), that led to the

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[26] For an example of such a model in an abstract city system, see S. Bond-Smith, P. McCann (2022) *The work-from-home revolution and the performance of cities.* Working Paper No. 026, The Productivity Institute.

use of a negative logistic interaction function rather than a negative power one in the labour market matching function.

11.3.10 Another dimension that needs to be considered is that the "access to…" measures so far considered are static in the sense that even though they change over time (and of course in response to transport interventions and land-use changes) they only measure access to what is there at the point in time considered. In labour market matching, however, the ability to attract the right person to fill a given job may also depend on attracting that person from another region or country; success in that may in turn depend on potential applicants being confident that they could find appropriate housing at an appropriate cost. This leads to two points which further research should ideally bear in mind:

- that labour market matching may depend on the housing conditions affecting potential residents, as well as on the labour supply already present;
- in addition to allowing workers to "permanently" live further from their jobs, remote working may play a "temporary" part in allowing workers to take up jobs to which they cannot immediately relocate.

11.3.11 Further dimensions of complexity arise from the facts that

- workers do not necessarily come singly; the possibility of regular remote working may also enhance labour market matching by making location choices easier for dual-career households[27];
- workers' locations are not necessarily independent of their preferences and possibilities for remote working – apart from the fact that remote working had been gradually increasing over the years before the dramatic increase resulting from measures to contain Covid-19, there has been considerable relocation during and since the pandemic. Better understanding how remote working influences employee's choice of where to work and where to live is particularly important, because that is highly relevant to a wide range of modelling tasks from conventional trip distribution models to the household and work location components of LUTI models.

11.3.12 The present author does not have a clear view as to how empirical research to meet these requirements might be carried out – or at least, not yet. Some ideas as to how methods might be identified are listed in the text box below.

Box 11:2 Ideas for further research

These notes do not attempt to propose exact questions or methods for further research, but set out some ideas which may be helpful in identifying appropriate questions and methods.

1	Is it possible to identify variables (or more probably, proxy variables) to measure the productivity effects of the different micro-foundations? Is it also possible to identify situations in which the suggested measures of A2EM for different micro-foundations are significantly different from one another (i.e. not strongly

[27] Or multi-career households: the present higher levels of not-so-young adults living with their parents must imply increased numbers of three- or four-career households.

	correlated with one another) – or better, to have changed in significantly different ways?
2	If it is not possible to identify any such situations (or not where data is available), is it possible to simulate them in hypothetical "experiments", as for example stated preference (SP) experiments can be used to obtain separate valuations of attributes which in practice are highly correlated with one another? This might not be possible: it is difficult to imagine SP experiments in which respondents would be able to say which of two alternatives would contribute more to productivity through agglomeration effects, as distinct from which one they would personally prefer.
	Could "imaginary experiments" (as in SP) be used to disaggregate overall agglomeration relationships estimated on observed productivity data? (as existing TAG sensitivities have been hypothetically disaggregated in chapter 7 of this report)
3	Is it helpful (or unhelpful) to try to estimate the impacts of remote working on agglomeration in the same analysis as the internal impacts of remote working i.e. in situations where there is a contractual relationship?
4	Rather than regarding location choices and changes as complications in the assessment of remote working effects, is it possible to uses those choices as indicators of remote working effects?
5	Should research into the agglomeration consequences of remote working be put aside until the more direct or overall consequences are better understood? More specifically, is it possible that the general effect of remote working on productivity is so dire that remote working should as far as possible be banned? Would the same conclusions be reached if remote working was considered in terms of wellbeing rather than of productivity?
6	Can/should research into the consequences of remote working (instead of commuting) be integrated with or separated from research into the consequences of remote meeting (instead of travel on business)? Integration would be desirable, because agglomeration benefits reflect both commute and business travel, but would potentially complicate the research further.
7	Whilst there is always a preference for using the most recent data, would it be possible to assess the impacts of remote working by comparing agglomeration effects "now" with those from (say) 20 years ago? NB this involves at least two more detailed questions: is it possible to assemble sufficiently consistent datasets - or better still, a very long time series of suitable data? and: is it possible to control sufficiently for all the other changes over the period considered?

11.3.13 The further text box below lists a number of related points that should be taken into account in further research in order to ensure that its results are applicable in practice.

Box 11:3 Desiderata for further research

Note: these are requirements that should be taken into account in designing and planning future research into agglomeration effects of transport. They are not proposals for that research, and they are not specific to remote working questions. Source: partly drawn from DSC/KPMG recommendations for further research developed in the course of project work for TfL, April 2016.

1	Transport should be considered explicitly i.e. "access to" should take account of transport supply, not just of distance; the scope and definitions of the data used should be clear to the end user of the research[28]
2	The representation of transport should take account of all relevant modes (including, if at all possible, modes which are only locally significant at present but may be more important in future e.g. cycling)
3	It is recommended that passenger modes should be considered as alternatives and that "access to" economic mass should be represented using a composite or average generalised cost based on appropriate choice theory e.g. a logsum measure, or a computationally practical alternative
4	If modal measures of A2EM are developed and used in estimating impacts on agglomeration (as in previous SERC work on agglomeration[29] and in ITS work on land value[30]) then the formulae used should be applicable to situations where economic mass is changing (i.e. dynamic agglomeration, in TAG terms) as well to those where only "access to" is changing (i.e. static agglomeration)[31]
5	Active modes should be included in the analysis (this implies a spatial scale fine enough to distinguish journeys where active modes are likely to be preferred)
6	Consideration should be given to alternative forms of the decay curve (e.g. the negative logistic used in the matching function for this report)
7	Consideration should be given to the possibility of non-linear or cumulative effects e.g. that agglomeration effects only occur once a certain level of A2EM has been reached (which may be different for different sectors, and at different levels of technological development)

[28] As an example of what to avoid: there is at least one paper in the literature which reports results including and excluding London, which are potentially interesting but practically impossible to interpret because the document does not say (and apparently the authors do not know) whether the "rail" mode considered in their analysis included or excluded travel by London Underground.

[29] Overman, H G, Gibbons, S, D'Costa, S, Mion, G, Pelkonen, P, Resende, G and Thomas, M (2009): *Strengthening economic linkages between Leeds and Manchester: feasibility and implications: full report*. Prepared by the Spatial Economics Research Centre (SERC), London School of Economics, for The Northern Way, Newcastle upon Tyne.

[30] J. Nellthorp, M. Ojeda Cabral, D. Johnson, C. Leahy, L. Jiang (2019): *Land Value and Transport (Phase 2): Modelling and Appraisal.* Final Report to TfN, WYCA and EPSRC. Institute for Transport Studies, University of Leeds.

[31] This relates to a point made by Professor Dan Graham in reviewing a project in which the SERC modal agglomeration formulae had been used to calculate productivity changes; he argued that it was inappropriate to apply the SERC formulae in circumstances where economic mass was changing. Subsequent discussion agreed that there was a methodological question to consider where modal formulae are used, but did not come to a conclusion.

8	Attention must be given to the distinction between “people” and “place” effects - though the distinction between “people” and “context” is preferred, to avoid giving the impression that different places have inherent or immutable advantages or disadvantages. “People” effects (on productivity) are those which result from the characteristics (including those of education and past experience) of the individuals in the workforce; “context” is everything else about the city or region; the key complication is that (as discussed in section 3) an attractive context may help to attract more productive people
9	Whilst it is probably necessary to use pay as a proxy for individual productivity in order to address “people” versus “context” issues, care should be taken in considering the relationship to GVA. ONS data suggests there are, potentially cyclical, variations in the relationship between wages and GVA at the national level and what look like more structural differences between sectors and (potentially as a result) between regions. There may be similar issues about other choices e.g. the use of firm-level total factor productivity measures (including the problem of multi-location firms).

11.3.14 Note in passing that points 4 and 5 together would allow analysis of the agglomeration consequences of alternative strategies for “15-minute cities” (e.g. concentrating housing around employment centres, or dispersing employment towards [existing] housing). This is a particular aspect of a more general question: how remote working, which allows and sometimes encourages workers to live far from their work and to make fewer but longer commute journeys that depend on motorised modes, interacts with policies to encourage the use of active modes, which are more suited to shorter journeys?

11.4 Closing comments

11.4.1 This project has of necessity been very much an exploration of ideas around the component micro-foundations of agglomeration effects and how they may be affected by different levels of remote working. It suggests that the general tendency of increased remote working will be to reduce the agglomeration benefits of transport improvements, but that this will not be uniform for all locations, for all schemes or for all the micro-foundations that are believed to contribute to agglomeration, and hence it may not be the case the remote working will reduce agglomeration benefits in all appraisals. The difficulty of conducting meaningful empirical research into the different micro-foundations is well known, and the need to take account of remote working in doing so adds to the complications.

11.4.2 These challenges need to be kept in proportion, in that agglomeration benefits are only one aspects of the benefits and malefits arising from transport (and other) projects, and they are also only one indirect aspect of the benefits and malefits arising from remote working itself. Moreover, these are inter-related: since it is clear that for many workers, a major part of the attraction of remote working is to avoid the cost, time loss and discomfort of commuting, improvements in transport should contribute to reducing the level of remote working. The economic benefits of reducing remote working might be more significant than the agglomeration benefits considered here. This study has treated the level of remote working as a given in each scenario, but the way in which it is influenced by transport needs further attention and would feed back into the consideration of agglomeration issues.

APPENDIX A COEFFICIENT SCALING AND COST DAMPING

A.1 Introduction

A.1.1 This appendix contains some further discussion of the coefficient scaling used in the logsum averaging of generalised costs over modes, as applied for the hypothetical city model, and about the comparison between this and the TAG cost damping method.

A.2 The case for coefficient scaling

A.2.1 To note first: if a logit model is defined so that the term inside the exponential is a generalised cost measured in minutes (typically including journey time and money cost divided by a value of time) multiplied by a coefficient – say lambda (λ) - then lambda is inversely proportional to the standard deviation of the distribution of the unknown (or "error") terms i.e. the differences between the true disutility that the individual traveller minimises, and the modelled disutility. These differences explain why some people choose an alternative other than the one which appears "best" in modelled terms.

$$p^m = \frac{\exp(-\lambda .g^m)}{\sum_a \exp(-\lambda .g^m)} \qquad (12.1)$$

then standard deviation in the "error" terms is proportional to $1/\lambda$.

A.2.2 Note that the units of λ are the inverse of the units of *g*. This ensures that (a) the exponential term calculates the exponential of a unitless number, and (b) the standard deviation of the "error" terms is in the same units as *g*. (And this is why if *g* is redefined in, say, £ rather than minutes, the value of λ has to be changed to compensate for the change in units.)

A.2.3 The coefficient adjustment proposed relates specifically to the meaning of λ. It's based not on empirical observation but rather on a "common sense" argument that the standard deviation of the "error" terms must surely be greater over longer distances: the range of variation in a 1km journey must be much less than the range of variation in a 500km journey. This is implemented by the value of λ decreasing as distance increases, so that the standard deviation of the "errors" increases with distance. This also has the intuitively appealing property that it makes it much less likely that the logsum composite over modes will come out negative (because the distribution of error terms will be much narrower at short distances where the generalised cost is small, meaning less of each distribution will be below zero and reducing the possibility that the composite will come out negative).

A.3 Relationship to TAG cost damping

A.3.1 Turning to cost damping as described in TAG[32], this represents two different effects:

(a) that the value of time (relative to money) increases for longer journeys;

(b) that the effect on choices of standard measures of generalised cost decreases at longer distances.

A.3.2 TAG is clear that these are distinct and that it is reasonable to implement both an increasing value of time and an overall scaling down of generalised cost as distances increase. What isn't clear from TAG is over what real distances these effects have been observed. For the moment we assume that the value of time increase is significant if comparing inter-city trips to intra-urban ones, but not significant over the range considered in the hypothetical city (up to about 45km between "surrounding towns" on opposite sides of the city).

A.3.3 For a mode choice model between two zones, the general cost damping will have a similar effect to scaling λ, and the two could be set up to have exactly the same effect. The difference is that the general cost damping will also directly affect destination choice, if that is above mode choice, whereas the scaling in λ will not directly affect destination choice (because it is "cancelled out" of the logsum calculation by the $(1/\lambda)$ term).

A.3.4 As far as the agglomeration is concerned, we believe all the research into elasticities and decay curves has been using, at the most sophisticated, straightforward generalised costs without any distance-based cost damping. Given that the theoretical case study is using logsums to calculate composite generalised costs over modes, we suggest it is more appropriate

- to use the distance-based scaling of λ in the logsum calculation, so as to get the effect that a 5-minute generalised cost difference between two modes matters less on a 45km cross-city trip than on a 500m intrazonal trip, and
- not to use a TAG-type overall cost damping.

A.4 Comparison of coefficient scaling with TAG cost damping

A.4.1 The logit mode split model with a distance-varying λ coefficient is

$$p_{ij}^{m} = \frac{\exp\left(-\lambda_{ij}^{M}.g_{ij}^{m}\right)}{\sum_{m}\exp\left(-\lambda_{ij}^{M}.g_{ij}^{m}\right)} \qquad (12.2)$$

where

[32] Unit M2.1, section 3.3. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/938855/tag-m2-1-variable-demand-modelling.pdf

g_{ij}^{m}	is the generalised cost of travel (or transport) from *i* to *j* by mode *m*, inclusive of any modal constant or other adjustment (e.g. higher weighting on time spent waiting or in congested vehicles)
$-\lambda_{ij}^{M}$	is a mode choice coefficient, varying with distance.

A.4.2 If we then define the variation of λ with distance as

$$-\lambda_{ij}^{M} = -\lambda_{REF}^{M} \cdot \left(\frac{D_{ij}}{D_{REF}} \right)^{\gamma} \qquad (12.3)$$

where

$-\lambda_{ij}^{M}$	is the coefficient to be used in averaging generalised costs over modes, to be calculated;
$-\lambda_{REF}^{M}$	is the given value of the coefficient at reference distance D_{REF}
D_{ij}	is the distance from *i* to *j* (upper-case variable, as lower-case *d* already used for the deterrent effect of distance or travel)
γ	is a coefficient determining how $-\lambda_{ij}^{M}$ varies with D_{ij}.

then the mode choice model becomes

$$p_{ij}^{m} = \frac{\exp\left(-\lambda_{REF}^{M} \cdot \left(\frac{D_{ij}}{D_{REF}} \right)^{\gamma} . g_{ij}^{m} \right)}{\sum_{m} \exp\left(-\lambda_{REF}^{M} \cdot \left(\frac{D_{ij}}{D_{REF}} \right)^{\gamma} . g_{ij}^{m} \right)} \qquad (12.4)$$

and the generalised cost model becomes

$$g_{ij} = \frac{1}{-\lambda_{REF}^{M} \cdot \left(\frac{D_{ij}}{D_{REF}} \right)^{\gamma}} \ln \sum_{m} \exp\left[-\lambda_{REF}^{M} \cdot \left\{ \left(\frac{D_{ij}}{D_{REF}} \right)^{\gamma} \right\} . g_{ij}^{m} \right] \qquad (12.5)$$

A.4.3 If one reads the distance-related term {in curly brackets} as scaling the generalised cost rather than scaling the coefficient, then the term in square brackets - i.e. the adjusted generalised cost used in calculating the composite cost - is the same as that specified by the cost damping equation at 3.3.11 in TAG Unit M2.1.

APPENDIX B IMPLICATIONS FOR AGGLOMERATION BENEFIT CALCULATIONS

B.1 Content

B.1.1 This appendix reviews the implications of the thinking and of the hypothetical city calculations for agglomeration benefits, particularly as compared with the present TAG calculations. This material is contained in two tables.

B.1.2 The columns of Table B.1 are as follows:

- id and Description identify the micro-effects originally introduced in PN1 and used in the hypothetical city calculations
- "Different in calculation" summarised what is different about the new A2EM measure (compared with that in TAG)
- "Implication for different types/ranges of transport" considers the effects of moving to the new A2EM measures
- the next column "Impact of increasing remote working on the changed calculations" considers how these measures will be affected by changes in remote working
- the final group of columns suggest how the changes in calculation and increases in remote working may jointly affect the results of agglomeration calculations for improvements to transport at three different spatial levels: (intra-)urban, (intra-) regional and long-distance (or inter-regional). The fields in the table say "MORE" or "LESS" where the changes are, other things being equal, expected to increase or decrease the agglomeration benefits.

B.1.3 The thinking behind these suggestions is explained further in Table B.2. Note that neither table attempts to indicate anything about the relative importance of the different agglomeration micro-effects.

Table B.1 How will the contributions of different effects to agglomeration benefits of different kinds of schemes be affected by increased remote working?

Source: own analysis and reflection

id	Description	Difference in calculation	Implication for different types/ranges of transport	Impact of increasing remote working on the changed calculations	Agglomeration benefits from different types of transport improvements: suggested variation from present TAG		
					Urban	Regional	Long
S1	Sharing "indivisible" (but potentially changeable) facilities e.g. a major airport	Considers access to specific facilities (as yet only an example [a major regional airport] has been specified)	Will depend on the facilities considered e.g. access to a regional airport depends mainly on urban and regional passenger travel (long-distance travel is more likely to be a substitute).	Unaffected by RW, though potentially impacted by remote meetings (RM) if facilities are relevant to business travel NB facilities used by workers in course of their working day (though not as part of their work itself) are counted at S5	MORE (especially if facilities are not major employers)		MORE (major national facilities)
S2	Sharing a larger pool of suppliers	Considers access to more specific supplier sectors, with more specific interaction decay effect	For obtaining commodity goods, many supplies will be national or international, so longer-distance freight movements will be more important	RW/RM assumed not to affect availability or delivery of physical supplies (i.e. assumed that firms will manage RW and RM to avoid any adverse effect; no indication that RW/RM would have any positive effect)	LESS	?	MORE
			For obtaining other goods and services, supplies will be more local and/or require business travel as well as or instead of goods movement	Again, RW is assumed not to affect supplies of goods and or services of these types (RM will have more effect)	No change	No change	No change
S4	Sharing larger pools of customers/clients	Considers access to more specific purchaser sectors, with more specific interaction decay effect	For sectors supplying commodity goods, many deliveries will be national or international, so longer-distance freight movements will be more important	Suggested that RW will not affect the production or delivery of physical outputs (as for S2)	LESS	?	MORE
			For other sectors, deliveries will be more local and/or require business travel as well as or instead of goods movement	Again, RW is assumed not to affect deliveries of goods and/or services (RM will have more effect)	No change	No change	No change
S5	Amenity value of services used by staff in particular locations				Mixed (MORE where such services are more than proportional to jobs, LESS where they are less than proportional or absent)	Not relevant	Not relevant
S6	Amenity value of services/facilities used by residents in general				Mixed, as for S5 above	Not relevant	Not relevant
M	Labour market matching	Replace job-to-job with job-to-labour measures, based wholly on passenger transport	Connectivity within/between major employment centres will be less important, connectivity between employment centres and residential zones will be more important	Following applies only to sectors where RW is feasible. Short or very short commutes may be little affected by RW, especially if they are largely made by walk/cycle or by people living in small dwellings. Medium to long commutes likely to be become less significant and improvements in these will contribute less to agglomeration benefits. Very long commutes (those which very few people would do daily, but might do one/twice a week) may become more relevant to agglomeration benefits.	Unchanged[33] or LESS	LESS or unchanged for sectors where RW is possible; unchanged or MORE for other sectors	Possibly MORE for sectors where RW is possible; unchanged for other sectors

[33] Note that the hypothetical city model applied levels of remote working that were uniform across distances and housing/household types, so did not take account of the possibility that people with short commutes, typically more likely to be living along and/or in small dwellings, may prefer to continue mainly commuting even if given the option of working remotely.

id	Description	Difference in calculation	Implication for different types/ranges of transport	Impact of increasing remote working on the changed calculations	Agglomeration benefits from different types of transport improvements: suggested variation from present TAG		
					Urban	Regional	Long
KG	Knowledge generation	Job-to-job travel-based calculation weighted by the advantage of in-person interaction, added to a measure of non-travel remote interaction	Connectivity within major employment centres will be most important, though less important than in existing calculations if remote interaction proves effective for knowledge generation	Major differences across sectors: expected that sectors involving physical skills will be unaffected (but they will be less or un-affected by RW in any case Reasonable to support (or at least hope) that firms will manage RW so as to maintain levels of KG and KD; interaction may therefore remain important	For sectors with significant remote working: probably LESS. Other sectors unchanged	For sectors with significant remote working: probably SLIGHTLY LESS. Other sectors unchanged	Probably unaffected
KD	Knowledge diffusion	Job-to-job travel-based calculation weighted by the advantage of in-person interaction, added to a measure of non-travel remote interaction	Connectivity within major employment centres will be most important, though less important than in existing calculations if remote interaction proves effective for knowledge diffusion		For sectors with significant remote working: probably LESS. Other sectors unchanged	For sectors with significant remote working: probably SLIGHTLY LESS. Other sectors unchanged	Probably unaffected

Table B.2 Explanation of the thinking behind the above suggestions

Source: own analysis and reflection

id	Description	Agglomeration benefits from different types of transport improvements: explanation of suggested variation from present TAG		
		Urban	Regional	Long
S1	Sharing "indivisible" (but potentially changeable) facilities e.g. a major airport	Implication is that schemes offering better access to/from these facilities will deliver greater agglomeration benefits, given that the facilities play no part in present agglomeration calculations. The effect will be even greater if the facilities are not major employment centres. (Some, notably major regional airports, are very significant employment locations, but the implication of this micro-effect is that such facilities have a significance for agglomeration and productivity over and above the economic mass represented by their employment.)		As for urban and regional, but long-distance transport probably only relevant to national facilities. NB this might include major ports for international trade.
S2	Sharing a larger pool of suppliers	Flows of standard or "commodity" goods are in many cases over long national or international distances. Calibration of a specific effect relating to the pool of suppliers for such goods is therefore likely to put more weight on long-distance freight transport than the existing formula, and corresponding to reduce the weight on urban/local transport. Regional transport may on balance remain unchanged i.e. with limited importance. Services and more specialised products (involving for example more negotiation prior to purchase or more technical support after) seem more akin to the kinds of job-to-job interaction implicit in the existing TAG A2EM measures; so it is not clear that any change will occur here.		
S4	Sharing larger pools of customers/clients	Same arguments as for S2		
S5	Amenity value of services used by staff in particular locations. NB as noted earlier, this needs further consideration to confirm that it is a contribution to productivity of the workers who use the amenities, and not just an S4 effect for the suppliers	This effect refers to services and amenities enjoyed by workers near their workplaces so… …only improvements in very local transport (e.g. to walking within city centres) will be relevant. Where such amenities are readily available (more than proportional to jobs), the agglomeration effect will increase, and vice versa	… regional and longer-distance travel are irrelevant.	
S6	Amenity value of services/facilities used by residents in general As above, the contribution from this effect to productivity (rather than simply to the welfare of residents) needs to be considered further	This suggested effect is not as localised as S5, but still local in scale. It would change the relative importance of different interventions e.g. better access to parks and open space would become much more important (than in the present calculations where importance depends on job numbers).	Similar to above: the scale of this effect is such that regional and long-distance transport are irrelevant	
M	Labour market matching	Improvements in urban transport would contribute less to agglomeration effects for sectors where remote working becomes significant. However, the workers in those sectors who may short commutes in larger cities are more likely to be younger and living in small dwellings, possibly alone or sharing. Given the lower disutility of a shorter commute, the social utility of the office environment and the inconvenience/discomfort of working at home,	For workers in sectors where remote working is common, longer-distance commuting (meaning over "typically long" rather than "exceptionally long" distances) makes remote working particularly attractive, especially as such commuters are more likely to be living in houses with space (and possibly spare rooms) suitable for working at home. Improvements in travel over such distances may therefore become less important as frequencies fall. On	Remote working may encourage some workers to take up jobs in workplaces implying exceptionally long-distance commutes, which they do only infrequently. This could mean that the contribution of long-distance passenger transport improvements (in practice, likely to be high-speed rail) to agglomeration effects could increase. Note that (i) major improvements in speed and frequency may effectively move "long-distance" commutes into the

id	Description	Agglomeration benefits from different types of transport improvements: explanation of suggested variation from present TAG		
		Urban	**Regional**	**Long**
		they are therefore less likely to choose to work remotely. This will limit the loss of agglomeration effect.	the other hand, respecifying the A2EM measure for this micro-effect will make connectivity between employment centres and residential zones more important, which may cancel out the effect of reduced frequencies. the change in the A2EM measure may make improvements at this range more important.	"regional" category (e.g. HS2 Phase 1 may make Birmingham to London a "regional" rather than a long-distance commute - though this also depends on details such as fares and booking/reservation arrangements) (ii) labour matching at long distances may be strongly influenced not only by residential relocation (commuters' households moving much further from their jobs) but also by more complicated possibilities such as commuting weekly between a remote main home and a city-centre second home. For other sectors, where remote working is not an option, improvements at this range will remain irrelevant.
KG	Knowledge generation	For sectors where remote working is significant, it will reduce the significant of improvements in transport which would facilitate knowledge generating/diffusing interactions. These interactions are most significant at within-urban levels, so the reduction is likely to be greatest in that category and least for long-distance travel.		
KD	Knowledge diffusion			