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AGGLOMERATION UNDER COVID

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Final report to Department for Transport

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Contents

ABSTRACT

This review considers how one of the side effects of the Covid-19 pandemic, that of homeworking, may impact on the agglomeration benefits that transport projects may deliver. There is substantial evidence on the extent of homeworking, and how this has changed during the pandemic. The evidence identifies that homeworkers during the pandemic are predominantly made up of urban based, white collar, well educated, service sector employees. The pandemic has increased the proportion of homeworking in each occupation and sector, but aside from possibly the administrative and secretarial occupations has not significantly altered the demographics of the homeworker. The pandemic also highlights a potential upper ceiling to the numbers of homeworkers of around 60% to 65% of the workforce in the core demographics that are suitable for homeworking. Over the whole workforce it is likely that only between 40 and 50% could work from home.

The literature contains much speculation about the future of homeworking and how this 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.

Aside from impacting on where people work, homeworking may impact on agglomeration benefits by changing the scale of the external benefits to agglomeration – by affecting the agglomeration elasticity and the decay parameter. We find that there is little empirical evidence that can 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 different micro-mechanisms that underpin agglomeration economies is very much concerned with demonstrating the relevance of the mechanism as a source of agglomeration economies, rather than identifying the proportion by which each mechanism contributes to agglomeration. This does not permit it to be used to estimate the potential for homeworking to enhance or erode the scale of agglomeration economies *ceteris paribus*. The only form of disaggregation possible is between the static (matching and sharing sources) and dynamic mechanisms (learning sources). Potentially homeworking may enhance matching mechanisms (by lowering average commute costs), but if learning mechanisms are dependent on face to face contact then these may be eroded. However, this is conjecture as evidence is non-existent on the impact of step changes in interaction costs. It is in our view unlikely that homeworking will 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. This is 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 is multi-pronged. Given the age of the current agglomeration parameters (agglomeration elasticity and decay parameter) and the need to better understand the role of transport costs in the ATEM function updating them would strike us as the most important aspect of research to pursue. In the short term this parameter updating could be undertaken using wage data such as from the Labour Force Survey (LFS) which already includes a 'rough' variable on homeworking. Enhancing the data collected in the LFS or using an alternative secondary data source would be a longer term option. In

terms of answering the question as to what the potential impact of homeworking will be on agglomeration benefits, this is clearly something that can explored in the short term using scenario analysis: based on estimates of homeworking, land use change and transport cost changes. Longer term a 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.

1 INTRODUCTION

1.1 Background and objectives

The global pandemic has caused an unparalleled shift towards homeworking, although it is currently uncertain to what extent this change will become permanent. Nevertheless, a higher level of homeworking is likely to continue post-Covid at least to some extent. This study has been commissioned to help the Department improve its overall understanding of agglomeration and its micro-mechanisms and thereby the potential long-term consequences of the coronavirus on transport appraisal practice.

This study has four main aims:

1. To provide a theoretical review of the principal micro-mechanisms thought to underpin agglomeration externalities, and how the impact of these might be affected by a permanent increase in homeworking.
2. To review and summarise any recent literature on the potential implications of Covid on agglomeration.
3. To identify relevant research questions that the Department should consider taking forward to better understand the impact of Covid on agglomeration under different scenarios.
4. To inform the Department's plans on future changes to appraisal guidance as evidence develops.

1.2 Report structure

The study has the form of a scoping report. It sets out the evidence on changes in homeworking and predictions on future land uses arising due to homeworking in Chapter 2. Here we find that there is substantial evidence on the extent of homeworking, but that it is very much concentrated in certain demographics. There appears to be much speculation about future land use change, but 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 in the future – commuting on the other days. This would imply that cities and city centres will continue to remain very 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. In Chapter 3 the evidence on the sources of agglomeration is reviewed and the evidence is summarised. Here we find that the empirical evidence on agglomeration economies is very much at an aggregate level and, whilst it indicates which micro-mechanisms are relevant, it does not really permit the aggregate agglomeration elasticities (such as in TAG) to be disaggregated – other than between the static and dynamic mechanisms. The final chapter, Chapter 4, sets out evidence gaps and research needs. The context is one of transport economic appraisal. It identifies the need for good data as well as specific investigations on land use change potential, the agglomeration model parameters and on the impact of homeworking on transport appraisals.

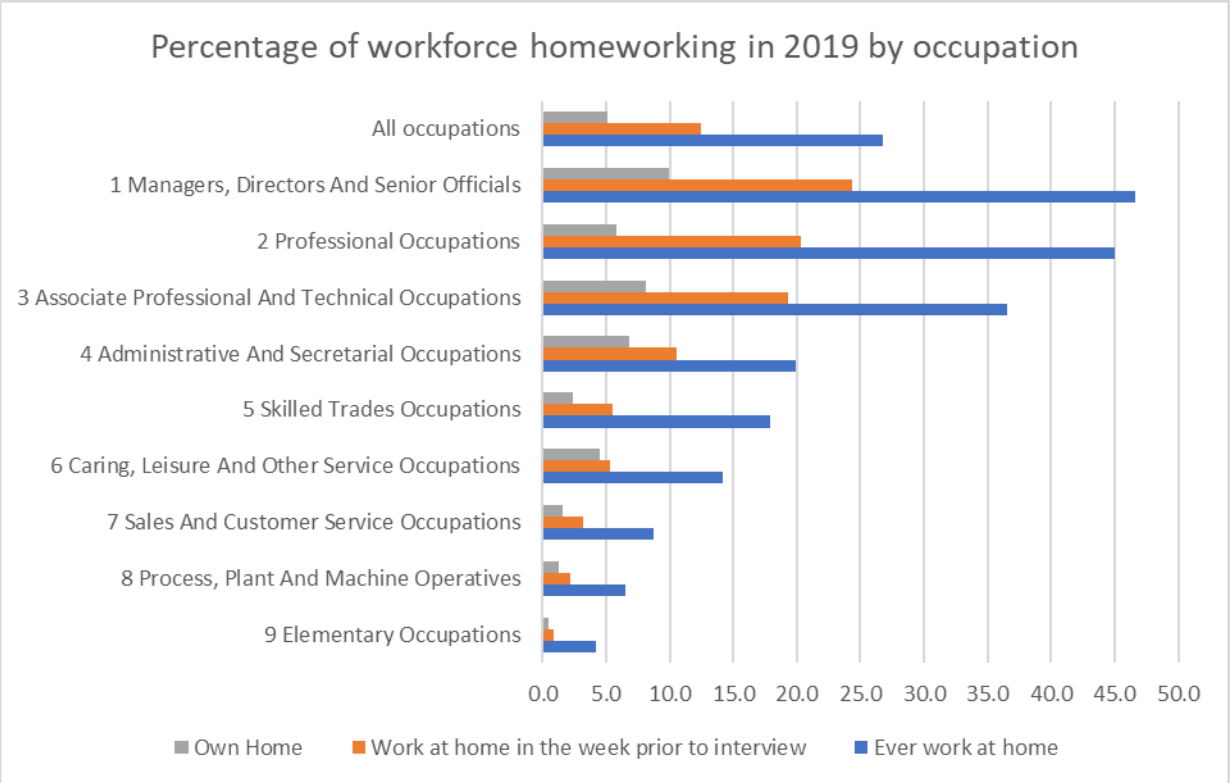
2 HOMEWORKING

2.1 Incidence of homeworking in the UK

Pre-pandemic 5.1% of workers in the UK mainly worked from home (Office for National Statistics (ONS), 2020a). This was approximately the same as the EU average, but about a third of the levels of the maximum levels of homeworking which are seen in the Netherlands and in Finland (Eurostat, 2020).

Experience of working from home however is much higher than the 5.1% who report mainly working from home. Across all occupations just over 25% of the workforce has experience of working from home (blue bar in Figure 2-1), with half that number having worked from home in the previous week to the survey. There is a systematic variation in the propensity to homework with occupation and industry. The higher skilled occupations are far more likely to have experience of home working and to have homeworked in the week immediately prior to the survey. 45% or more of highest two occupational categories have experience of working from home, with again just under half that having worked from home in the previous week to the survey. Furthermore nearly 80% of those who worked from home in the week prior to interview or who ever work from home, come from the first three major occupational groups (Office for National Statistics (ONS), 2020a).

FIGURE 2-1: PERCENTAGE OF WORKFORCE HOMEWORKING IN 2019 BY OCCUPATION



Source data: Office for National Statistics (ONS) (2020a)

Reflecting this variation by occupation Felstead and Reuschke (2020) find that propensity to work from home varies systematically with highest qualification. Almost half of graduates do some work from home, whilst just over 10% of those with no qualifications have worked from home. In terms

of income Felstead and Reuschke find that the highest earners sometimes or often work from home. Those never work from home or who always work from home earn the lowest. The self employed are also over represented in the homeworking category.

Ability to work from home not only varies with the type of task that is being undertaken but also by the industry in which employment occurs. Where industries are workplace orientated or consumer facing such as manufacturing, transportation, warehousing, accommodation services, food services, tourist attractions, health and delivering consumer services it clearly would be difficult for people to work from home. For these sectors we see limited amounts of homeworking (see Figure 2-2). The two largest industrial sectors (accommodation and food services and health and social work) which comprise just over 25% of the workforce are very workplace orientated with only just over 15% ever having worked from home.

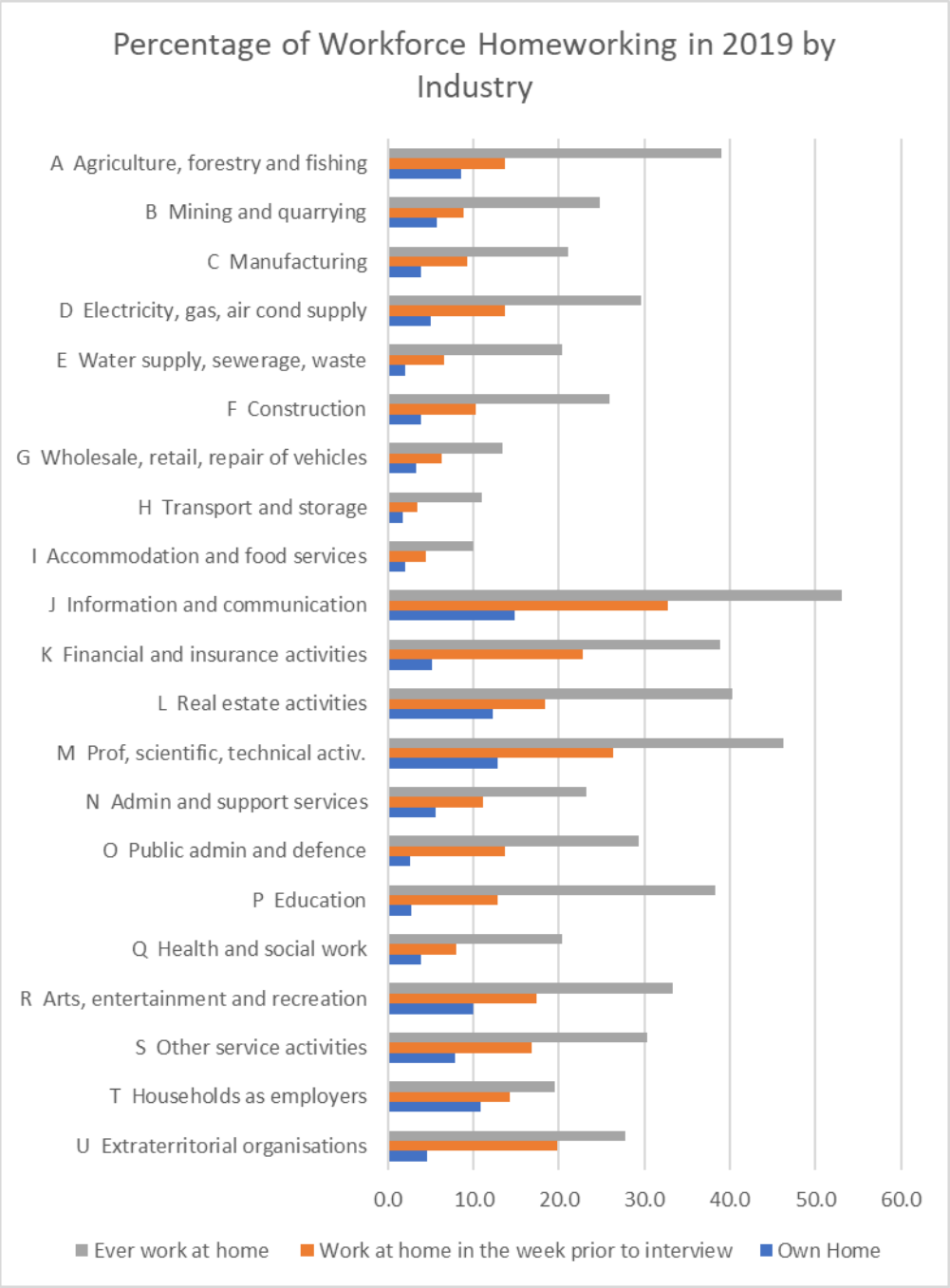
In contrast the information and communication sector and professional and scientific sector both had around 50% of people who have experience of homeworking and a large percentage who homeworked in the previous week to the interview. Along with financial and insurance and real estate activities these sectors comprise about 18% of the workforce. The education sector is interesting as preparatory work can be undertaken from home, but educational activities in schools and other educational institutions use classroom style methods – thus there is a low number of workers whose home is their main place of work, but there is a large number who do some work from home.

Felstead and Reuschke (2020)'s survey confirms these data as they find that "over three-quarters of workers in manufacturing (79.4%), construction (73.4%) and hotels and restaurants (85.9%) are required to work exclusively on employers'/clients' premises. This compares to around half of those working in banking and finance (55.4%) and other services (58.1%)".

Clearly with propensity to work from home being determined by occupation and by industry there will also be regional variation in homeworking. As we can see from Figure 2-3 homeworking is more prevalent in London, South East and interestingly the South West. The ONS data does not disaggregate to a smaller spatial scale, but given the concentration of industries and occupations that exhibit high levels of homeworking in city centres we would expect workers in city centres to exhibit higher tendencies to homeworking than those who work in businesses elsewhere.

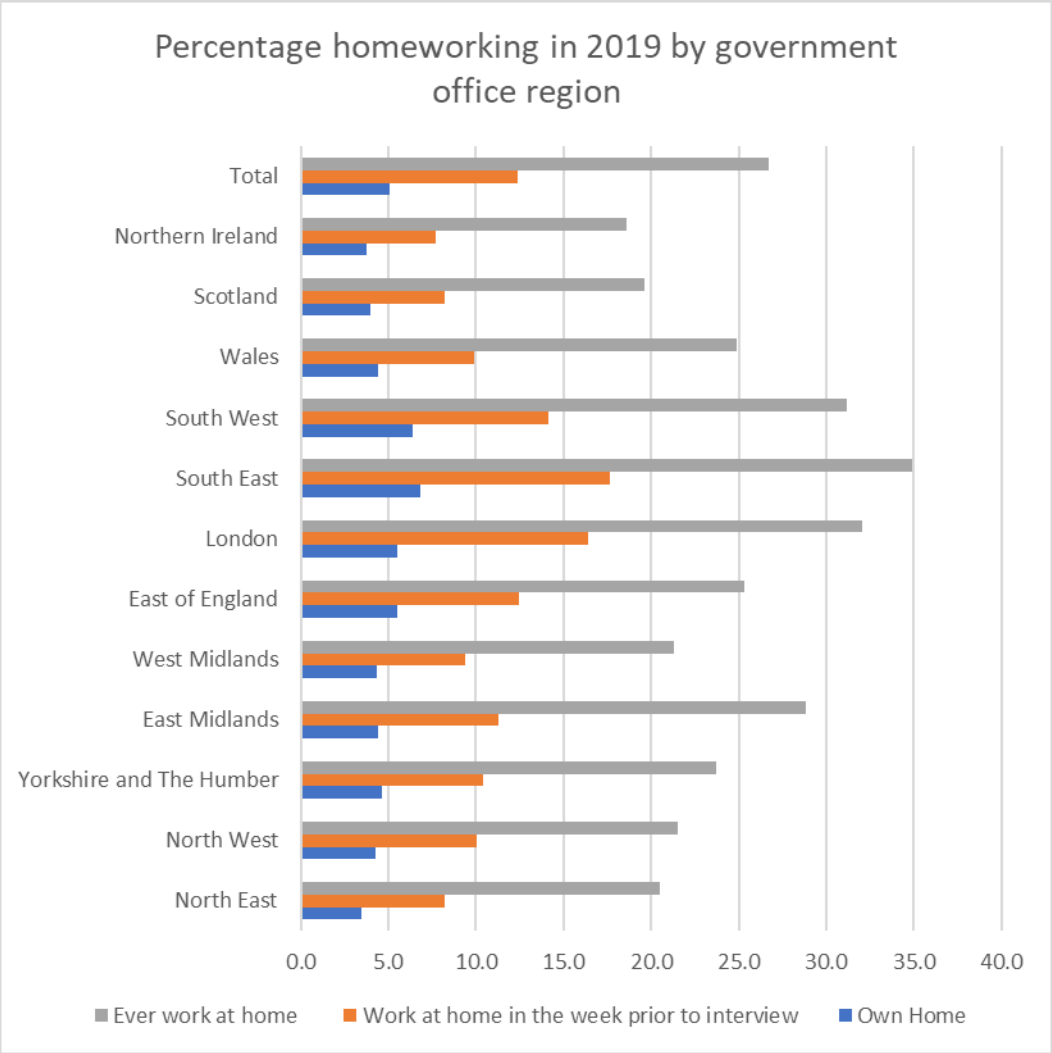
Recent contributions looking at the potential for homeworking identify that in the US 37% of jobs can be undertaken at home (Dingel and Neiman, 2020). These jobs represent 46% of all US wages – it is the higher paying (and more productive jobs) that are more likely to be able to be undertaken at home. There is a lot of heterogeneity by industry in their predictions. There is a very high potential (at above 75% of jobs) for certain industries, for example educational services, professional, scientific and technical services, finance and insurance and information to be undertaken from home, ranging to a very low potential (below 15% of jobs in that industry) for others (e.g. retail, agriculture, mining, accommodation and food services). Extrapolating their model to the UK predicts they predict that just over 40% of jobs in the UK can be undertaken from home. Survey work in the UK identifies that 46% of workers sampled consider that they could work from home (Department for Transport, 2021).

FIGURE 2-2: PERCENTAGE OF WORKFORCE HOMEWORKING IN 2019 BY INDUSTRY



Source data: Office for National Statistics (ONS) (2020a)

FIGURE 2-3: PERCENTAGE OF WORKFORCE HOMEWORKING IN 2019 BY REGION



Source data: Office for National Statistics (ONS) (2020a)

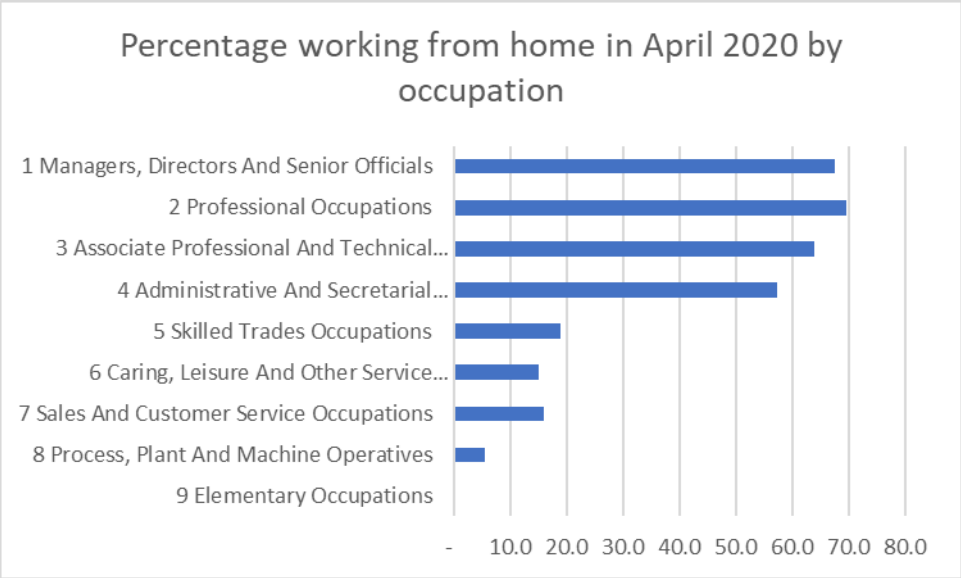
2.2 Impact of the pandemic on homeworking

The pandemic has had a massive impact on homeworking. In late March 2020 the government issued an order to work from home if it was possible. As the pandemic progressed and the virus was suppressed towards and during the summer of 2020, this led to a gradual easing of restrictions and in August 2020 an encouragement of a return to the workplace where it was deemed appropriate.

At the height of the restrictions in April 2020 45% of the working population did some work from home in the interview week, up from 25% who did some work from home in the week before the interview pre-pandemic (Office for National Statistics (ONS), 2020b). The number who work continuously from home is lower and has varied during the pandemic – ranging from between 20% of the workforce to 38% (Department for Transport, 2021) and compares to the 5.1% who worked mainly from home pre-pandemic (Office for National Statistics (ONS), 2020b). These work from home statistics are of a similar order of magnitude to homeworking proportions during the pandemic across European economies (Eurofound, 2020) and the US (Brynjolfsson et al., 2020).

Once again the demographic split reflects the pre-pandemic characteristics. Amongst the top three occupations just over 65% did some work from home in the reference week, an approximate trebling compared to pre-pandemic levels (Office for National Statistics (ONS), 2020b). The more practical and customer facing occupations also experienced a similar proportional increase but from a much lower base. The largest proportional increase was for the administrative and secretarial occupations where there was almost a six fold increase to just under 60% of workers doing some work from home in the reference week. Such administrative and secretarial occupations are likely to be more mobile in where the work can be undertaken than the practical and customer facing occupations, but pre-pandemic it is possible that such workers were not given the same work from home privileges as higher skilled occupations.

FIGURE 2-4: PERCENTAGE OF WORKFORCE HOMEWORKING IN APRIL 2020 BY OCCUPATION

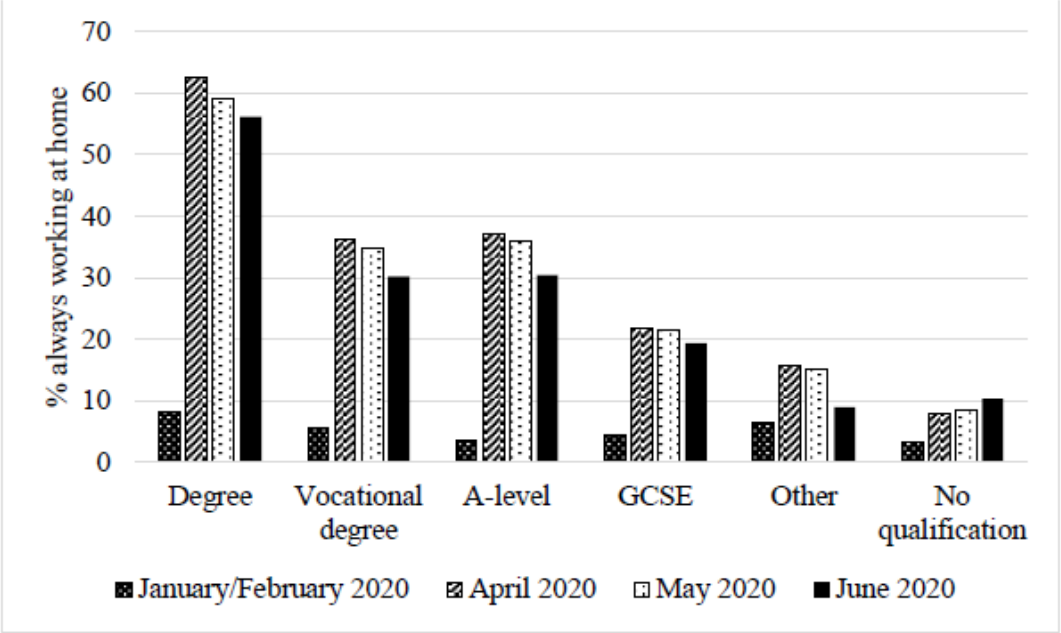


Source data: Office for National Statistics (ONS) (2020b)

Reinforcing these demographic differences regarding homeworkers during lockdown Felstead and Reuschke (2020) report that 60% of those with degrees made exclusive use of the home during lockdown, whilst only 10% of those with no qualifications made such exclusive use of their home as a workplace. Industry differences also prevail with 60% of those in banking and finance working exclusively from home during the pandemic, whilst between 15 and 20% of workers in distribution, hotels and restaurants did[1]. Regional differences then follow again from that with more than 50% of workers in London working exclusively from home, whilst about a third of workers in Wales working exclusively from home.

[1] FELSTEAD, A. & REUSCHKE, D. 2020. HOMEWORKING IN THE UK: BEFORE AND DURING THE 2020 LOCKDOWN. *WISERD Report, Cardiff: Wales Institute of Social and Economic Research.* . excluded furloughed workers from their analysis.

FIGURE 2-5: PERCENTAGE OF WORKFORCE WORKING EXCLUSIVELY FROM HOME IN EARLY 2020 BY QUALIFICATION



Source: Felstead and Reuschke (2020 Figure 7)

The conclusion from these surveys is that homeworking during the pandemic is predominantly made up of urban based, white collar, well educated , service sector employees. The pandemic has increased the proportion of homeworking in each occupation and sector, but aside from possibly the administrative and secretarial occupations has not significantly altered the demographics of the homeworker. The pandemic also highlights a potential upper ceiling to the numbers of homeworkers of around 60% to 65% of the workforce in the core demographics that are suitable for homeworking.

2.3 Labour supply and productivity with homeworking

At the height of the first wave of the pandemic in the UK (April 2020) around one third of respondents reported working more hours than usual and one third reported working less than usual (Office for National Statistics (ONS), 2020b). The other third reported no change.

The survey did not identify reasons for either of these. There are a number of plausible explanations. In April 2020 childcare and schools were closed and this will have impacted on hours available in a negative manner, so some workers may just not have been able to supply the amount of labour they had previously. Felstead and Reuschke (2020) also report that some workers found that they had less work to do as a result of the pandemic. Such arguments support reductions in the supply of labour. Arguments supporting an increase in the supply of labour would be associated with the lack of childcare and schooling impacting negatively on productivity[2]. Workers who

[2] Ibid. report that a third of workers reporting a drop in productivity cited childcare and home schooling reasons.

increased their labour supply may therefore have had to work longer to achieve the same outcomes. Alternatively, workers with long commutes may have transferred some of their previous commuting time to additional work. Their rationale for doing so could maybe be associated with expected future income gains from either promotion further down the line and/or more job security in a time of uncertainty.

There have been a number of UK surveys of self reported productivity changes from homeworking during the pandemic.[3] A survey of employers suggested there had been no change on average in productivity (i.e. similar numbers of employers suggesting increases in productivity as decreases) (CIPD, 2020). Felstead and Reuschke (2020) ask respondents their reported productivity and find that similar to the ONS labour supply findings that a third report falls in productivity, a third no change and a third an increase. The implication being that on average there is no change in productivity. As mentioned above a lack of work to do and childcare issues were major contributor to falls in productivity. Other reasons however were also cited including motivation, access to workplace resources interaction with colleagues more difficulty with post-covid work procedures. Interestingly in Felstead and Reuschke (2020) survey the productivity increases seemed to be driven by those workers who always work from home pre-pandemic. Etheridge et al. (2020) also find that UK workers productivity has not on average been affected by homeworking, and also identify systematic differences between different groups of workers. Workers whose jobs easily translate to homeworking experience increases in productivity, whilst those whose jobs do not experience decreases. Related to this is those who previously had some experience of working from home experienced productivity increases, whilst for those who had no experience there was generally a decline in productivity pre-pandemic. There is a gender split too with females suffering lower levels of productivity, which they attribute to the types of job and the requirement to also cover childcare. In a different survey Lee and Tipoe (2020) find on average a small decrease in productivity of between 2 percent (men) and 4 percent (women) from a shift to homeworking. With their focus on time use and not outputs, they define productivity as the ability to engage with work related tasks without distractions. Effectively therefore they only focus on the inputs to an economic productivity calculation, as they do not examine whether a person is more efficient per minute or hour of labour. They also find that gender roles in the labour market (in the types of jobs women do versus men) and in the household (women are less likely to have a personal workspace and are more likely to have childcare responsibilities) play a part. Childcare issues do however affect the productivity of homeworking for both men and women in the household, it is just that on average they affect women more.

Other surveys on productivity changes due to the pandemic show similar findings. In the Netherlands worker productivity was self-reported as being slightly less (Rubin et al., 2020), in Canada a third reported higher productivity, whilst the remainder have experienced no change or a reduction (Saba, 2020). In the US Feng and Savani (2020) find gender differences with women on average experiencing less job satisfaction and productivity than their partners (in dual-career households).

[3] Data sources for UK Covid, homeworking and productivity studies: ibid. use data from the Understanding Society Covid-19 Study based on a pre-existing household panel survey that started in 2009/10 and was rapidly adjusted to help study the impact of Covid. ETHERIDGE, B., WANG, Y. & TANG, L. 2020. Worker Productivity during Lockdown and Working from Home: Evidence from Self-Reports. *Covid Economics,* 52**,** 118-151. use the Covid-19 module from the UK Household Longitudinal Survey (UKHLS) administered monthly since April 2020. LEE, I. & TIPOE, E. 2020. Time use and productivity during the COVID-19 lockdown: Evidence from the UK.: Oxford University. use a sample specifically recruited for their research.

Clearly, pandemic initiated homeworking is confounded with household pressures on childcare, schooling and workload plus organisational changes facilitating remote working procedures. It is therefore hard to draw any conclusions at the moment on the impact of homeworking on labour supply and productivity post-pandemic. In terms of robust pre-pandemic evidence homeworking does indicate potential for productivity improvements. In a well cited study on a Chinese call centre Bloom et al. (2015) find productivity improvements of 13%, which increases to 22% if workers are allowed to self-select homeworking[4]. In a US study on patent examination Choudhury et al. (2020) also find productivity gains. They find that a shift to exclusive homeworking (from a situation of part homeworking) increases work output by 4.4%. Both studies have similarities: they focus on a single organisation and the tasks homeworkers are required to do are relatively independent of other workers. Both organisations also made certain pre-requisites of their homeworkers, including have spent a certain amount of time in the office before being allowed to homework and having certain facilities available to them (e.g. internet connectivity and a personal workspace). In the Chinese context workers were also required to spend a day a week in the office -so were not exclusive homeworkers.

In terms of the types of task that are most suited to homeworking Dutcher (2012) finds that for students working from home improves productivity of creative tasks but compromises productivity of dull tasks. Whilst not a study of homeworking Battiston et al. (2020) find that in the 999 call handling department of Greater Manchester Police worker productivity is enhanced through co-location. Here the ability to communicate face-to-face improves worker performance when workers perform inter-connected but discrete tasks – in this case taking the initial call (the handler), and directing the emergency response (the radio operator). Clearly the type of tasks, the variety and the requirement to exchange information effect the ability of workers to work remotely and therefore productivity.

To summarise robust empirical evidence on the productivity of homeworking is thin and what does exist, whilst intuitive, is best described as embryonic. Furthermore, the evidence that does exist does not address productivity of workers who require co-ordination with other workers at a moderate to extensive level, nor does it address the efficiency of on-the-job learning whilst homeworking. The latter being very pertinent to our interests.

2.4 Future projections of homeworking in the UK

The empirical work undertaken to date shows that a significant number of workers wish to continue homeworking at least some of the time. In the pan-European Eurofound (2020) survey 78% of respondents indicated an interest for working from home at least occasionally post-pandemic, with the largest preference for several times a week (32%), but with only 13% indicating that they would homework daily. 13% of workers homeworking is currently at the levels seen in the Netherlands and Finland and about 2.5 times the current EU and UK average. Felstead and Reuschke (2020) report similar results for the UK with approximately nine out of ten workers who have experienced homeworking during lockdown wishing to keep working from home in some capacity post-pandemic. They also report that 13% of workers would wish to work from home all the time post-pandemic, and only 11.8% reported they would not want to do any homeworking. Most respondents (75%) report they would like to work from home either ‘sometimes’ or ‘often’ post-

[4] The implication here is that workers who experience productivity improvements at home tend to self select to homeworking, whilst those who do not tend to self select to working in the office.

pandemic. Other survey data shows similar higher proportions who wish to maintain some form of homeworking post-pandemic (Department for Transport, 2021).

These early studies also suggest that it is the workers who have had the most positive experiences of homeworking during the pandemic in terms of mental well-being and productivity, which are often correlated (Etheridge et al., 2020, Feng and Savani, 2020), that are more likely to indicate that they will homework in the future (Rubin et al., 2020, Saba, 2020, Felstead and Reuschke, 2020). For the Chinese call centre case study presented earlier (Bloom et al., 2015) once homeworking was opened out to all workers the productivity increase went up to 22%, with the difference to the trial homeworking experiment attributed to self selectivity of workers. The expected self-selectivity by workers for homeworking post-pandemic, Felstead and Reuschke (2020) conclude, would increase not reduce productivity should employees be allowed to work at home if they want to. Aligned with that is the expectation by businesses that there will likely be a doubling of homeworking post-pandemic (CIPD, 2020) with 74% of small company directors expecting to keep more homeworking and 53% expecting to reduce their long term use of workplaces (Department for Transport, 2021).

These results suggest that post-pandemic there will be a strong shift to more homeworking, with the majority of those who have been able to homework during the pandemic wishing to continue to do so in some capacity. They do not however suggest that the levels of exclusive homeworking we have seen during the pandemic will be maintained at anywhere near their current levels post-pandemic. Having said that at 13% of workers permanently homeworking this represents just over a doubling of exclusive homeworkers in the UK, which is quite sizeable.

2.5 Implications for the city and agglomerated city centres

The shift to homeworking during the pandemic has led to a number of authors to speculate on the future of the city and of city centres as we know them. Nathan and Overman (2020) postulate three different scenarios, which differ in how long it takes to exit the pandemic. The longer the exit period the more different a city would look, with the pandemic acting as a nudge towards new types of behaviour with more suburban living and working (with more consumer service businesses in the suburbs). Those vulnerable to the disease and able to homework avoiding cities, and city centres in particular, due to the risk of catching the disease. This may make the demography of city centres even younger. Nathan and Overman (2020) do not seem to conjecture a demise of the city, but more a re-allocation of space within and between cities (front of office functions in city centres, back office functions in suburbs, headquarters in larger cities, with smaller cities specialising in production), though countenance that this is hard to predict.

In a special issue of *Environment and Planning B* edited by Michael Batty a number of authors consider the role of the city post-Corona. This is speculation for the moment as the authors recognise with different viewpoints being espoused:

> We may well see walkable cities emerge, we may well see much more work from home, a decline in redundant international travel, a move to produce more locally and cities built around health care. But we may see much more sprawl as people seek to get away from big cities to small towns, we may see a growth in car travel and a decline in public transport, we may see countervailing trends reinforcing each other such as working from home at much farther distances away from cities, we may see more social isolation, and different kinds of social epidemic related to changes in our health and longevity.

Batty (2020)

In that issue Couclelis (2020) considers that cities will be resilient to the pandemic because in her view homeworking does not offer the panacea that some make out it does, and cities offer amenities and the opportunities for social interactions to households as well as places to work. Kellerman (2020) offers views similar to Nathan and Overman (2020). That is the post-Corona city will not be a revolutionised one, but is one in which a wider range of activities will shift to virtual channels, which may bring about changes in urban land-uses – but it is too early to say what. Kleinman (2020) offers a view that cities will still being an important part of our landscape, but possibly a re-distribution of activities will occur within the city, with a possible reduction in 'densification'. Florida et al. (2020) similarly argue that there will be little change in economic geography with the dominance of the global cities, but at the micro-geographic scale there is likely to be some structural changes affecting a city, its suburbs and its metropolitan region. Other authors in the special edition conjecture on the opportunity of Covid to alter how our cities function in terms of addressing structural problems of inequality (Lozano-Gracia, 2020), allocating urban space away from the car (Hidalgo, 2020), the use of technology and changes in city form to mitigate climate change (Yamagata and Yoshida, 2020), and an increase in undertaking activities local to the household (Talen, 2020). Interestingly none of these authors argue that cities will demise, but just that cities will change.

In a recent theoretical piece looking at the impact of working from home Behrens et al. (2021) identify that the relationship between homeworking and productivity and GDP is n-shaped. Productivity increases with some working from home, but negative impacts can also occur on productivity if there is an excessive downscaling of workplaces. Their model also predicts, as has been observed by other authors, that homeworking increases economic inequalities. Using a general equilibrium model of Los Angeles featuring local agglomeration externalities and endogenous traffic congestion Delventhal et al. (2021) find three important effects on land use change as a consequence of a large scale shift to working from home. Firstly, jobs move to the core of the city, while residents move to the periphery. Secondly, traffic congestion eases and travel times drop. Thirdly, average property prices fall, with declines in core locations and increases in the periphery. They find that workers who are able to switch to homeworking enjoy large welfare gains by saving commute time and moving to more affordable locations, whilst workers who continue to work at the workplace enjoy some welfare gains due to lower commute times, derived from improved access to jobs, and the fall in average real estate prices. In a sister paper Delventhal and Parkhomenko (2020) consider the implication of wide spread homeworking across the whole US. On average they find a shift in the balance between cities from large coastal cities to smaller interior ones, and from central to peripheral areas. Jobs not only increase in these peripheral locations, but also cluster in the highest productivity metropolises. What happens to agglomeration economies is critical to whether these land use changes have net beneficial effects. If agglomeration externalities are retained then welfare effects are positive, but if homeworking leads to a reduction in productivity through agglomeration (through less face-to-face interactions) then wages fall and most workers are worse off.

A shift to homeworking is also expected to impact on the location on consumer service businesses such as restaurants, cafes, pubs, hairdressers, gyms and some retail. These sort of business activities would be expected to follow the location of where workers are based. The mis-match between where local consumer service businesses are currently based (in city centres) and where they would be required under large scale homeworking is arguably large (De Fraja et al., 2020). The interrelationship between where workers work and where consumer services businesses wish to locate therefore could lead to some significant land use changes should homeworking become very prevalent.

The early survey data on pandemic homeworkers preferences for homeworking post-pandemic is also indicative of continued city living, with the majority of pandemic homeworkers expressing a preference for splitting their time between their workplace and their home post-pandemic. The implication is that there will not be an exodus from the city, but rather a reduction of commuting trips and spreading of commuting trips across city regions (Reuschke, 2020). Based on the proportion of established homeworkers living in rural and urban areas (70% urban, 30% rural) the options for telecommuting may also free up residential location choice with approximately 10-15% of workers being able to re-locate (Reuschke, 2020). This is a substantial proportion of households, but it does not represent the end of the city. It is also subject to some frictions as not all respondents to the survey will be able to enact their preferences due to employer and household constraints (e.g. requirement to be at the workplace on certain days, school age children, or access to healthcare). It is also worth noting that Felstead and Reuschke study did not ask respondents about future residential location choice, either whether they would move to an alternative location within their city, to another city, or to a smaller settlement or a rural area – so there is a degree of speculation in her estimate of the potential number of those who would move home into rural area.

Undoubtedly though commentators, businesses and employees themselves are expressing a viewpoint that there will be substantially more homeworking in the future. This is clearly going to have implications for city centres, as it is very likely that the homeworkers employer will be based in a city centre – given the demographic of the pandemic homeworker: urban based, white collar, well educated, and service sector. Whilst there appears to be a consensus that the role of cities will remain important, but that there will be changes within the city as to where activities occur how this pans out will fundamentally be dependent on how the transport and land markets react.

In one transport and land use scenario we could envisage that demand on the transport system will fall substantially, this may lead to public transport service cuts as operators struggle to maintain financial viability, leading to further falls in demand and further transport service cuts, etc. (the Mohring effect). This could make the city centre more inaccessible. Working against that would be a reduction in car traffic flows and road congestion, thereby making city centres more accessible. With less commuters coming into the city centre there will be a reduction in the consumer services available in city centres (food and drink and retail), though this will also depend on whether there is any demographic change with city centres getting younger (as per Nathan and Overman).

In another transport and land use scenario we may envisage that hot desking becomes the norm and the capacity of the city centre to host workers therefore increases – as all workers begin to hot desk. If any spare capacity freed up on the transport system or in city centre floor space is taken up by businesses re-locating to the city centre with more people now commuting to the city centre (albeit on fewer days of the week) then at the extreme cities could become very large. For example, if every worker attends the workplace only 50% of the time, then potentially the city centre could accommodate double the number of workers. Potentially therefore this could lead to a relocation of workplaces towards the city centre from suburbs or even smaller cities. Whilst workers would reduce the number of weekly commuting trips, the average commute would have to increase to meet this change in land use. Whether the existing transport system could accommodate that would be very context dependent.

In each of these scenarios also lies variations associated with how the provision of consumer facing services would locate, from only a small reduction in city centre activities to a large reduction – with a shift to the suburbs. Additionally, there is also the likelihood that some workers will look to re-locate. Felstead and Reuschke (2020) found a just over doubling of workers expressed a preference to work exclusively from home. One might presume these workers would be prime for changing

residential location and in doing so they may place more demands on the inter-urban transport network, which may or may not be able to be supplied post-pandemic.

In conclusion it seems very likely that post-pandemic the role of the city will continue to be very important in the economic geography of countries like the UK. How activities are organised post pandemic within a city could change and different directions of change are possible. The direction and scale of change will be contingent on the land and transport market reactions, and potentially could lead to profoundly different outcomes for city centres. On one hand city centres might be a lot quieter than they were pre-pandemic, but judging from the stated intentions of employees will certainly not be at pandemic levels of very low activity. On the other hand a scenario could be envsiaged in which more people commute into city centres (albeit not at the same time). Government's role in this does not have to be passive as it has the levers to steer society one way or another via incentives and investment. This also applies for issues on inequality, climate change and quality of living.

3 AGGLOMERATION ECONOMIES

3.1 Agglomeration economies in aggregate

Cities exist partly because firms, workers and households obtain benefits from co-locating with each other. One of these benefits relates to the consumption benefits of households – the way they interact, socialise and consume services (e.g. education, healthcare, retail, leisure services) with more diversity available in cities (Glaeser et al., 2001). Agglomeration economies is another. These are the productivity benefits that firms experience from co-locating. There are however also economic costs to co-locating in terms of congested networks, crime and high rents.

The net impact on business productivity of the benefits and costs of co-locating, the aggregate agglomeration economies, have been well studied. The broad consensus is that agglomeration economies give rise to an increase of productivity of between 4 and 11% for a doubling of city size (Eddington, 2006), corresponding to an elasticity range of between 0.03 and 0.08 (Rosenthal and Strange, 2004). There is however a large range in estimated elasticities. In their meta-analysis Melo et al. (2009) found a mean value of 0.058 with a standard deviation of 0.115, a 5th centile of -0.09 and 95th centile of 0.292. This variation is not random. Melo et al. (2009)'s analysis indicates service industries benefit the most from agglomeration, whereas manufacturing sits around the economy wide average. Study characteristics also matter as the results vary systematically with the data utilised and the empirical strategy adopted. The Graham et al. (2009) agglomeration elasticities used by DfT in their TAG guidance conform to these general observations. The average economy wide elasticity is 0.04, with higher observed elasticities for producer services sector 0.083 compared to manufacturing (0.021), construction (0.034) and consumer services (0.024). Ahlfeldt and Pietrostefani (2019) in their recent meta-analysis find an average agglomeration elasticity for wages of 0.04 which doubles for developing countries.

3.2 Homeworking and the empirical estimation of agglomeration economies

Our interest is how a change in homeworking post-pandemic may impact on these agglomeration elasticities. As we have seen earlier (see Figure 2-1) the number of workers who split their time between their workplace and home was already substantial pre-pandemic. The propensity to do so also varies systematically with occupation and industry. Across all occupations some 13% of workers worked from home at some point in the week prior to being surveyed in the ONS' Annual Population Survey (Office for National Statistics (ONS), 2020a), but for the top three occupations this increased to between 20 and 25%. Clearly therefore the international evidence base on agglomeration elasticities that we are familiar with embodies an element of homeworking already.[5] The changes post-pandemic are therefore an extension of this, rather than being a new phenomenon. Ideally, therefore the existing evidence base on agglomeration elasticities could be utilised to understand the post-pandemic impact of a step change in homeworking.

Unfortunately, our search of the literature has not identified any specific references to the treatment of homeworkers in the estimation of agglomeration elasticities. There are no references

[5] The Department's agglomeration elasticities were estimated in 2010 using panel data from the Annual Respondents' Database (ARD). Homeworking patterns are likely to have changed significantly over this timeframe.

to homeworkers in the classic handbook references: Rosenthal and Strange (2004) and Combes and Gobillon (2015); nor in Graham and Gibbons (2018) which concerned itself explicitly with the empirical estimation of agglomeration economies or the recent review piece by Duranton and Puga (2020). Economic mass, as measured by employment, is typically a key determinant of empirical work examining agglomeration economies. As far as we are aware these empirical agglomeration studies do not differentiate between workers who are based full-time at the workplace, those who work some days of the week from home either occasionally or regularly or those who work exclusively from home (for a business located elsewhere). Workplace data is collated from secondary sources. Where firms are multi-plant firms and it is not clear from the data source being used at which site workers may be based, then these multi-plant firms are cleaned from the dataset (see e.g. Holl (2016)).

In summary, there has been no specific treatment of homeworkers in the estimation methodologies employed. The existing evidence base is on the aggregate agglomeration impact is therefore of little assistance in understanding the impacts on the elasticities of a post-pandemic increase in homeworking. We therefore turn to an examination of the micro-foundations of agglomeration economies and evidence on their relevance and size. We can then use this evidence to interpret potential impacts on agglomeration of an increase in homeworking.

3.3 Microfoundations to agglomeration economies.

3.3.1 Marshallian sources

Following Marshall (1890) the classic 'sources' of agglomeration economies are:

- Knowledge spillovers
- Labour market interactions/pooling
- Linkages between intermediate and final-goods suppliers

There has also been a substantial research effort to identify the empirical relevance of different Marshallian sources of agglomeration economies. This is reviewed in Rosenthal and Strange (2004). This type of empirical analysis is difficult as the different sources of agglomeration economies are heavily correlated. Strategies adopted include identifying proxy variables for the different mechanisms and then examining whether these proxy variables are significant. This empirical work is therefore heavily dependent on the strength of the proxies adopted. Knowledge spillovers are the hardest to identify in this framework due to a difficulty in finding suitable proxies (Rosenthal and Strange, 2004 p2150). There is evidence of all three Marshallian sources. These studies if a mechanism is relevant, and in doing so can also identify relative strengths of the different sources. However, they are primarily descriptive and do not disaggregate an agglomeration elasticity between the different sources of agglomeration economies. In their review of the relative strengths of the different mechanisms Combes and Gobillon (2015) consider that "Rosenthal and Strange (2001) are typical of this kind of study. Whereas labour pooling has a positive effect, knowledge spillovers have a positive impact on spatial concentration only when they are measured at a small scale (the zip code). Reliance on manufactured inputs affects agglomeration at the state level but not at a smaller scale."

3.3.2 Micro-foundations

These Marshallian 'sources' are however now regarded as aggregate effects or outcomes of agglomeration economies. As such they maybe confounded with other benefits of reduced transport and communication costs in agglomerations. Why confounded? It is because agglomeration economies are specifically external economies of scale. Firms and individuals by clustering together receive benefits that are external to themselves. That is the system as a whole performs better than if each part was separated out and the impacts from each part summed. In understanding agglomeration economies therefore, we need to conceptually disentangle the direct benefits of better connectivity which can be internalised to the firm or individual from the spin off benefits – the external economies of scale. Thus, lower commuting costs in a large labour market are internal to the firm/individual, but better quality matches and the reduced risk of larger labour markets are sources of external benefit to the firm and individual. Similarly, reduced transport costs in buyer-supplier relationships are internal to the firms in the supply chain, but the improved variety of goods on offer in larger agglomerations is an external benefit.

It is these spin off benefits that are now considered to be the micro-foundations to agglomeration economies. The classic reference here is that by Duranton and Puga (2004) who set out ten sources of external economies of scale in cities, categorising them into three basic typologies of *sharing, matching and learning*.

Partly due to the empirical issues associated with early work understanding the Marshallian sources, empirical work on the micro-foundations has been characterised by trying to identify whether particular mechanisms are significant, rather than trying to disentangle the agglomeration impact across the different mechanisms. The different micro-foundations and examples of the evidence that supports their existence is presented in Table 3-1 to Table 3-3. The content of these tables have been drawn from Duranton and Puga (2004), Puga (2010) and Duranton and Puga (2020). Ultimately though this avenue of empirical works is once more descriptive of which microfoundations are relevant. If we are interested in understanding the scale of the impact of homeworking on the agglomeration elasticity we would need to look to an alternative evidence base. Here the literature on static and dynamic agglomeration has something to offer.

Static and dynamic agglomeration refers to the process by which the agglomeration economies occur. Static agglomeration mechanisms relates to the productivity benefits that are fixed. For example, the inherent characteristics of a city make all workers in that city a bit more productive. If they leave that agglomeration then that productivity uplift is lost – as it is fixed to the agglomeration in which they had worked. These are typically associated with the matching and sharing channels discussed above. Dynamic agglomeration benefits channels or mechanisms relate to the manner that agglomerations may change productivity over time. These are associated with rates of learning. Higher rates of learning, and human capital creation, diffusion and accumulation will be associated with the larger city. An important element of the dynamic mechanisms is that the productivity uplift gained is transferable from one place to another. Thus, a worker who learns in a larger city becomes more productive than a worker who learns in a smaller city, and if they move cities are able to transfer some of this additional learnt productivity with them. This categorisation should not be confused with UK transport practitioner terms of static and dynamic clustering, which relate to changes in land use – though of course there is an inter-relationship.

The empirical work in this field is of interest as it tends to disaggregate the agglomeration elasticity between static and dynamic components – with the static component being attributed to sharing

and matching, whilst the dynamic is attributed to learning. Carlsen et al. (2016), Korpi and Clark (2017), and de la Roca and Puga (2017) all report urban wage growth premiums over time, and interpret this as evidence that dynamic learning effects are at play in cities. Using Norwegian administrative data Carlsen et al. (2016) find that the learning effect on labour productivity reaches a plateau after approximately 10 years. The learning effect is strongest for those who are college-educated. Their model implies that a worker with average job tenure in Oslo receive a 17% wage premium of which just under 60% is attributed to dynamic effects. Using Spanish data de la Roca and Puga (2017) attribute a similar proportion of the observed urban wage premium to dynamic effects. In contrast, D'Costa and Overman (2014) only find evidence that learning in a city leads to faster productivity growth for those who have worked in a city, compared to those who have never worked in a city, and that the benefits of learning are complete within a year. In part, these discrepancies between these different studies stem from the empirical difficulties in separating the effects of how workers of different qualities sort themselves into different cities, from the static and dynamic premiums and the inter-relationship with different skill sets and how these different skills sets benefit from agglomeration. The implication from this albeit small sample is that dynamic effects (namely the *learning* sources) make up the majority of the observed agglomeration economies, with *matching* and *sharing* sources taking the remainder.

TABLE 3-1: SHARING MICRO-FOUNDATIONS

Sharing micro-foundation[1]	Example evidence [2]
Sharing indivisible goods and facilities. Indivisible goods and facilities are associated with large fixed costs and congestion. Market places, parks and transport services all constitute examples of indivisible goods. The sharing of these goods is one of the reasons cities exist. If the transport investment provides new or significantly enhanced transport capacity (e.g. a new train station or airport) this will immediately become available to the residents of that city. New transport infrastructure will also strengthen an agglomeration, giving more people access to existing shared facilities (e.g. market places). A third channel will also exist as the transport investment may lead to the creation of new shared facilities. Venables et al. (2014 Appendix 4.1) discuss this in the context of office or shopping development.	Burchfield et al. (2006) find that residences are closer to each other in cities where water provision relies on shared public facilities, whereas urban development is more scattered in areas where cities' aquifers make individual household wells viable.
Sharing the gains from variety. Final producers become more productive when they have access to a wider variety of intermediate suppliers. Improved transport links by connecting cities together, or making the effective city larger, increase the number of intermediate firms available to final producers thereby increasing productivity of the final producers.	Rosenthal and Strange (2001) find that sharing a common base of suppliers is a source of agglomeration, but weaker than the other Marshallian sources. Overman and Puga (2009) find that businesses cluster if their supply chain is also clustered. Ellison et al. (2010) find that sectors buying similar intermediates tend to co-agglomerate the most, followed by sectors that employ similar workers. Holmes (1999) finds that the most concentrated industries buy more inputs from outside suppliers in locations they are clustered than in the rest of the country. He also finds that purchased-inputs intensity of a plant also increases with the level of employment of neighbouring plants in the same industry.
Sharing gains from individual specialisation. The underlying argument here is that the increased output within large agglomerations allows task or individual specialisation. Increased specialisation is more productive than each worker doing a bit of every task. Duranton and Puga also refer to this as 'learning by doing'.	Baumgardner (1988) shows that physicians perform a narrower range of activities in large markets. Holmes (1999) shows firms are more individually specialised in large markets (and outsource supplies). The work of Holmes (1999) and Michaels et al. (2019) can also be seen as supporting the role of specialisation in more concentrated markets – with Holmes considering the firm and Michaels the city.
Sharing risk. One of the benefits of labour market pooling is that firms, which face random increases or decreases in demand, are less constrained by the size of the labour market. For example, a firm that faces a positive shock, and wishes to take on more workers, will face paying a lower wage premium in a large labour market relative to a small labour market. In these circumstances the variance in the wage faced by the firm decreases the larger the labour market pool is.	Overman and Puga (2009) find that sectors that experience more idiosyncratic volatility in employment are more spatially concentrated, even after controlling for a range of other industry characteristics.

Note 1: Source: Duranton and Puga (2004)
Note 2: Source Puga (2010) and Duranton and Puga (2020)

TABLE 3-2: MATCHING MICRO-FOUNDATIONS

Matching micro-foundation[1]	Example evidence [2]
Improving quality of matches. In the economy there is a heterogeneity of tasks and skills and small skill mis-matches will lower productivity. The same argument applies between suppliers and final good producers. An increase in the number of agents trying to match improves the quality of the match. Thereby increasing productivity. A transport improvement increases the number of agents within a certain travel time and therefore would be expected to improve the quality of the matches.	Whilst intuitive the difficulty of empirical work on this mechanism is gathering evidence on quality of matches (Puga, 2010), which limits the number of studies. Büchel and Ehrlich (2020) use mobile phone data to identify that shorter travel times make interactions more likely, but rather than increasing the number of interactions people are more choosy who they interact with. The implication is that interactions are between better matches. Dauth et al. (2018) use matched employer-employee data for Germany to show that high-quality workers (those who get high wages conditional on observables) are more likely to work for high-quality firms (those who pay high wages conditional on observables) in denser cities. This assortative matching reinforces the fact that high-quality workers and firms are also more likely to locate in denser cities.
Improving the chances of matching. Here the argument is positioned that job search and recruiting is subject to frictions. In this situation a proportional increase in the number of job seekers and job vacancies results in a more than a proportional increase in the number of matches. The net result is that in larger cities we expect there to be less unused resources (e.g. lower unemployment levels) ceteris paribus.	Gan and Li (2004) find that in an academic recruitment market for new PhDs in economics, that a field of specialisation with more job openings and more candidates offers a higher probability of matching. Costa and Kahn (2000) show that couples in which both spouses have college degrees are increasingly likely to be located in the largest metropolitan areas, and not just because they meet there. This could be due to the higher chance that they can both find employment in larger cities.
Mitigating hold up problems through ease of matching. A potential problem to economic growth can occur if assets are specific but cannot be observed – for example a worker's skills. The firm cannot observe the worker's skills until they employ her. This can lead to a situation in which worker's do not invest in skills. In larger labour markets there is a larger market place for skills and this problem is mitigated. A similar argument can be extended to other assets.	Neither Puga (2010) nor Duranton and Puga (2020) identify any empirical studies for this micro-foundation.

Note 1: Source: Duranton and Puga (2004)
Note 2: Source Puga (2010) and Duranton and Puga (2020)

TABLE 3-3: LEARNING MICRO-FOUNDATIONS

Learning micro-foundation[1]	Example evidence [2]
Knowledge generation. A learning process is required to generate new knowledge. Arguably this learning process is higher in the larger diversified cities where there exist more opportunities to utilise different skills, techniques or production methods. Arguably a transport improvement that increases learning opportunities can intensify such learning processes.	Duranton and Puga (2001) find that firms in France create products in large cities and re-locate to smaller cities to produce it. Audretsch and Feldman (1996) show that innovative activity, as measured by significant new product introductions tend to cluster geographically to a greater extent in industries where new economic knowledge plays a more important role. This spatial concentration of innovation holds after controlling for spatially concentration of production. Atkin et al. (2019) use mobile phone data that gives a high degree of spatial location (to the level of spending time in the same coffee room for 15 mins) to study how chance meetings contribute to innovation. They isolate smartphone users who work in buildings belonging to tech companies in Silicon Valley and trace instances where the users are in the same place at the same time. They separate chance from planned meetings and show that chance meetings result in more patent citations across firms in different sectors whose workers had met by chance more often.
Knowledge diffusion. Here the argument is that proximity to individuals with greater skills or knowledge facilitates the acquisition of skills and the exchange and diffusion of knowledge. That is after a transport improvement which increases the size of an agglomeration the rate at which knowledge is diffused will increase.	Jaffe et al. (1993) track knowledge flows by looking at patent citations. They show that inventors are much more likely to cite prior patents with inventors from the same city than a randomly drawn control sample of cited patents. No (2003), using data on the adoption of advanced manufacturing technologies in Canada, finds that adoption is more likely in locations with more prior adopters, particularly if they use similar technologies but do not compete in the same detailed sector. Charlot and Duranton (2004) use survey data on communication between workers to show that workplace communication is more extensive in urban areas. In addition, more workplace communication is associated with higher wages.
Knowledge accumulation. Larger cities are argued to be reservoirs of more knowledge. This stems from their ability to accumulate knowledge. In contrast to the previous two learning mechanisms, which relate to changes in rates of knowledge generation and diffusion, this reflects an absolute amount of knowledge. As a consequence, this is likely to be a medium to long term effect.	Neither Puga (2010) nor Duranton and Puga (2020) identify any empirical studies for this micro-foundation.

Note 1: Source: Duranton and Puga (2004)
Note 2: Source Puga (2010) and Duranton and Puga (2020)

3.4 Relevance of agglomeration economies in a digital age

Our interest in homeworking and agglomeration has at its heart the relevance of agglomeration economies in a digital age. Therefore it is worth looking at the paradox between falling transport and communication costs and the relevance of agglomeration. Borrowing the words of Edward Glaeser:

> Agglomeration economies are the benefits that come when firms and people locate near one another together in cities and industrial clusters. These benefits all ultimately come from transport costs savings: the only real difference between a nearby firm and one across the continent is that it is easier to connect with a neighbour. Of course, transportation costs must be interpreted broadly, and they include the difficulties in exchanging goods, people, and ideas. The connection between agglomeration economies and transport costs would seem to suggest that agglomerations should become less important, as transportation and communication costs have fallen. Yet, a central paradox of our time is that in cities, industrial agglomerations remain remarkably vital, despite ever easier movement of goods and knowledge across space.
>
> Glaeser (2010 p1)

Digital technologies in the form of mobile, email, and video calling contribute to a reduction in communication costs as they can act as a substitute for travel. But digital technologies go further than that and have and are expected to continue to assist with a lowering of transport costs. Improvements in electronic control mechanisms on railways reduce costs there by facilitating both an increase in capacity, and lowering unit operating costs. Electric vehicles are cheaper to run than their hydrocarbon equivalents, and one would expect autonomous vehicles to lower transport costs further. We have also seen that homeworking as a substitute for travel and communication is quite prevalent – even before the pandemic. So digital technologies contribute in multiple ways to reductions in transport and communication costs and yet the dominance of cities in our economic landscape never seems to have been stronger.

Glaeser and Ponzetto (2007) identify how improvements in communication technology create two opposing forces that act on cities. The first erodes the benefit of being located in the city and leads to dispersion of activities away from the city. However, improvements in transportation and communication technology can also increase the returns to new ideas, by allowing those ideas to be used throughout the world. Cities that specialise in producing goods may therefore lose out under improved digital communications, whilst cities that produce ideas will benefit from improved communications. This is therefore one explanation for the survival of cities with large amounts of human capital, but as Glaeser and Ponzetto (2007) also indicate that cities specialising in manufacturing will diminish as digital communications improve. This they say appears to fit some of the urban facts about urban change in the US, where cities like New York have thrived and cities like Detroit have struggled.

Similarly Michaels et al. (2019) see that a lowering of transport and communication costs induce urban areas to specialize according to their comparative advantage, which is in interactive tasks. Using micro data from the United States from 1880 to 2000, they find an increase in the employment share of interactive occupations within sectors over time that is larger in metro areas

than non-metro areas, that these increases in employment in interactive occupations in part relate to improvements in transport and communication technologies. This they identify highlights a change in the nature of agglomeration over time toward an increased emphasis on human interaction.

This is consistent with the overall position advocated in New Economic Geography where in developed countries we see dispersion of manufacturing from core regions to peripheral regions (Krugman, 1998, Lafourcade and Thisse, 2011, Combes et al., 2011) and the importance of density in the generation and diffusion of knowledge (Duranton and Puga, 2001, Puga, 2010, Duranton and Puga, 2020).

Returning to the micro-foundations and the Marshallian sources presented earlier. The different agglomeration forces these give rise to are almost certainly likely to operate at different geographic scales. As Rosenthal and Strange (2020 p28) in their review on the spatial reach of agglomeration economies identify: "the sharing of physical inputs, for example, is often associated with truck transport and can extend over regional distances. Labor market pooling is likely to have effects within commuting areas, which is to say at the metropolitan level. Knowledge spillovers as envisioned by Marshall (1890) are unplanned and are likely to be highly local". Whilst playing out over different spatial scales agglomeration effects are strongest between close neighbours. They cite evidence on the co-location of similar businesses in neighbourhoods, buildings and even within the floors of buildings as evidence of the importance of very close proximity. The need for close proximity is most likely associated with face-to-face interactions – the Marshallian knowledge spillovers and the Duranton and Puga learning effects. Some of these can be substituted for via information technology, such as interactions between known contacts. However, an element of the driving force to agglomeration economies relates to unplanned interactions (see e.g. Atkin et al. (2019) and Rosenthal and Strange (2020)), which would be hard to replicate via information technology.

Whether digital media can replace the function of face-to-face interactions in their role in driving agglomeration economies remains an open question. Rosenthal and Strange (2020) think not. They see that whilst information technology allows for effective communication with distant partners, these distant interactions are complementary to in-person interactions facilitated by close proximity. Networks that are developed in close proximity can be maintained via information technology should the members of those networks become distant. They conclude:

> In sum, improvements in information technology have still left us with agglomeration economies that operate at both broad and narrow spatial scales. Information technology clearly allows for productive distant interactions. One example is a radiologist reading an x-ray from a remote site. Other examples include the increasing use of video conference business meetings that take advantage of increasingly effective remote communication software, reinforced by distant interactions necessitated by the coronavirus pandemic. Nevertheless, both through direct and indirect channels, a range of evidence all points to continued benefits from proximity at narrow levels of geography, including neighborhood, building, and even within building locations.
>
> Rosenthal and Strange (2020 p45)

3.5 The measurement of Access To Economic Mass (ATEM)

Access To Economic Mass (ATEM) is typically a function of employment proximity (Duranton and Puga, 2020, Rosenthal and Strange, 2020) and is also the basis of the TAG calculation of ATEM. These employment type measures reflect business to business proximity. This makes sense for the sharing and learning micro-foundations. For example, businesses need to be proximate to one another if they are to share the labour pooling benefits with each other, otherwise commuting costs will likely shrink that benefit. Similar arguments can be applied to other the sharing and learning micro-foundations. We refer to this as business-to-business connectivity (B2B). The matching micro-foundations seem more closely related to labour market size, and a business to business measure might not therefore seem appropriate. Instead an employment by place of residence or a population function might be more relevant. We refer to this as business to consumer connectivity (B2C).

Graham and Gibbons (2019) compare ATEM functions calculated using an employment and population functions for Great Britain. Their employment function is a B2B function, whilst their population function is between consumers (so C2C). They find that the measures are highly correlated (correlation coefficient of 0.95), but that differences exist for the locations with the highest density of employment – namely Central London and some city centres. Their opinion is that it would make little difference which measure is used for economic mass due to these correlations. Additionally, the high level of correlation between the two measures makes it difficult to use both measures in the same empirical estimation. Thus in practice, whilst not ideal, a choice between the two mass measures invariably has to be made in empirical work – see KPMG (2013) for an example of the empirical challenges of mixing ATEM functions[6].

The use of a single economic mass variable (e.g. B2B) and correlation between the different mass variables (e.g. correlation between B2B and B2C) would imply that even though we would associate the different mass variables with different microfoundations then a single mass variable is likely to give a good empirical model for agglomeration effects. This is what is typically found with well fitting models (in a statistical sense) using just a single mass variable.

The ATEM function is also characterised by a decay variable. In a lot of the agglomeration literature such a decay is not usually considered explicitly. In fact little mention of it is made in the general agglomeration literature (see e.g. Duranton and Puga (2020), Rosenthal and Strange (2020)). Graham and Gibbons (2019) however discuss the importance of it in capturing the attenuation of agglomeration effects, which is particularly relevant in transport appraisal applications. The use of a single elasticity however also implies the use of a single decay parameter. Thus the empirically estimated attenuation of agglomeration elasticities with distance reflect an average over all the different micro-foundations. If however the different agglomeration elasticities are estimated by industry, then as we expect the importance of the different micro-foundations to vary by industry

[6] KPMG 2013. HS2 Regional Economic Impacts. Report for HS2 Ltd. Report dated Sept 2013. in work for HS2 Ltd used an accessibility function that disaggregated accessibility into four mass measures. Two B2B measures (road and rail), and two B2C measures (road and rail). As they stated in the report (see p51) "the four connectivity measures are correlated with one another. While each of the connectivity variables shows a positive and statistically significant relationship with productivity when tested separately, due to the correlation between them, it has not been possible to directly estimate their relative importance using a statistical approach." KPMG therefore created a merged model to estimate the total impact on productivity and disaggregate between the 'mechanisms'. This final model had no statistical basis and formed the crux of the substantial criticisms levelled out the work.

then these different industry decay parameters will reflect the attenuation of agglomeration with distance for the different mixtures of agglomeration micro-foundations per industry. Industries for which learning effects are likely to be important will have a high attenuation, whilst ones where input sharing is very important are likely to have a low attenuation.

To summarise the empirical estimation of agglomeration elasticities is challenging due to multi-collinearity issues amongst other things. The result is that compromises on the granularity and sensitivity of the ATEM variable to the different micro-foundations has to be made invariably through the choice of a single economic mass variable (usually employment i.e. B2B) and a single decay parameter. Though with respect to the latter disaggregating by industry can allow the different distance attenuation rates for the different agglomeration forces to come through more explicitly.

4 Discussion and research questions

4.1 The need for research

How does a change in homeworking play into the agglomeration framework set out in the previous chapter? To frame this discussion it is useful to think of the agglomeration productivity benefits equation in TAG as a three step process[7]:

1. Calculate ATEM. For example with the power decay functional form used in TAG:

$$ATEM_i = \sum_j \frac{E_j}{GTC_{ij}^{\alpha}}$$

Where: $ATEM_i$ is the ATEM of zone i
E_j is employment in zone j
GTC_{ij} is the generalised transport cost between zones i and j
α is the decay parameter in the power decay functional form

2. Calculate the percentage change in productivity due to the change in transport costs.

$$\theta_i = \left(\frac{ATEM_i^{DS}}{ATEM_i^{DM}}\right)^{\rho} - 1$$

Where: θ_i is the percentage change in productivity in zone i
ρ is the agglomeration elasticity
DM is the Do Minimum scenario, and
DS is the Do Something scenario

3. Calculate the economic benefits arising from changes in agglomeration ($WI1_i$)

$$WI1_i = \theta_i GDPW_i E_i$$

Where: $GDPW_i$ is the GDP per worker in zone i
$WI1_i$ is the GDP impact in zone i (known as Wider Impact 1 (WI1) in TAG terminology)

Within this formulation we expect homeworking to act through several channels. Firstly, through transport costs and land use changes. It will affect the number of people working in each zone the

[7] These equations have been simplified to abstract from differences between industrial sectors, aggregation of generalized transport costs across modes and time periods, differences in the functional form of the decay function (e.g. power decay or exponential), whether the ATEM function should be based on access between businesses, access between businesses and households or both, and where land uses change as a consequence of the transport scheme. The equations are consistent with the TAG definition of ATEM (for a single industry and time period scenario).

E_j in steps 1 and 3. How the transport market reacts to these changes in employment location will then alter the transport costs - GTC_{ij} in the above formulas. The impact of these transport cost and land use changes is discussed in section 4.2 of this chapter, section 4.3 with respect to the use of commuting costs in this GTC_{ij} calculation, and in section 4.4 with respect to the use of average commuting costs over the week rather than per trip in the calculation

Homeworking may also impact on the productivity associated with agglomeration. It could affect the level of productivity in a city zone arising due to clustering (the absolute level of productivity) by for example making cities effectively bigger with a larger labour market or alternatively effectively smaller if workers move out of the city, which makes it difficult for firms to interact. This is because if working from home impacts negatively on worker interactions *ceteris paribus* then we may expect the absolute level of productivity due to agglomeration to diminish. It could also alter the productivity change that a transport improvement could create – that is the agglomeration benefits. This could arise through a number of channels. It could arise because the base levels of productivity differ with and without extensive homeworking, that is the $GDPW_i$ term in Step 3 has altered. It could arise because the percentage change in ATEM due to the transport improvement changes. This would be as a result of either a change in the levels of ATEM (e.g. due to employment changes), changes in average GTC and/or changes in the distance decay parameter. This would feed into the calculations in the ratio $\frac{ATEM_i^{DS}}{ATEM_i^{DM}}$ in Step 2 above. Finally it could alter if the agglomeration elasticity and its associated decay parameter alter. These are ρ and α in the above equations in Steps 1 and 2 above. Whether these alter with extensive homeworking will depend upon the potential for worker interactions to increase, decrease or remain unaffected following a transport improvement.

How the agglomeration parameters may change as a consequence of homeworking is discussed in Section 4.3 by considering the each of the micro-foundations to agglomeration. At this point it is worth identifying that these assessments are judgemental. There is minimal evidence to draw on. Arguably mass homeworking is a result of a step change in interaction costs. Such costs include not only travel costs but also impedance costs associated with forming and breaking contracts, communication costs digital, paper, language translations and different institutional frameworks. Unfortunately, as Rosenthal and Strange (2020) identify there is no literature on how dramatic reductions in interaction costs impact on the spatial scale of the economics of agglomeration economies. This not only sets a need for further research, but also means that our assessment of potential impacts from working from home on the agglomeration parameters in the above equations to be judgemental.

The impact of homeworking on agglomeration benefits via the channels outlined above is discussed in Section 4.4. This is along with the implication of changes in homeworking on the formulation of the ATEM function and interaction with other elements of TAG (namely labour supply).

4.2 Land use and transport cost changes

A key point that stands out from the evidence base to date is that the impacts of working from home on agglomeration will vary by industry, primarily because the prevalence for homeworking varies by industry. We have seen that homeworking is most prevalent in urban industries and professional occupations, which are likely the ones that gain from digital connectivity. It is not that prevalent in industries which are tied to workplaces such as in manufacturing, construction or some consumer services. The future increase in homeworking is therefore expected to occur in these urban service sector industries, rather than construction, manufacturing and consumer service industries. Some of the evidence to date points towards some positive impacts of homeworking on productivity, and

self-selectivity by workers who experience productivity gains to choose homeworking options. These individual worker productivity gains need to be tempered with the recent theoretical contribution by Behrens et al. (2021) suggesting productivity will start to diminish should too many employees work from home. In a competitive market we would therefore expect different firms to determine a mix of homeworking and workplace working that maximises learning, innovation and productivity. We have for example seen different announcements by companies on their attitudes to homeworking, very likely reflecting the tasks undertaken by staff, and how they interact with other staff. On one hand financial businesses such as Goldman Sachs and JP Morgan have indicated that working from home will be limited whilst tech companies have indicated a much freer choice in working from home for their employees (BBC, 2021b). Companies with a mixture of office based and workplaced fixed workers have indicated they will allow some flexibility for office based staff. For example, BP has asked its office based workforce to work from home 40% of the time (BBC, 2021a) and Nationwide is allowing its office based staff to choose where they work from with full-time work from home is acceptable (BBC, 2021c). No doubt these different business responses to work from home opportunities are partly a function of the role that learning, apprenticeship and innovation play within the respective organisations vis a vis 'back office' functions.

The very specific businesses that are likely to permit working from home mean that changes in land use will be very much focused around these businesses as they reduce office floor space in response to increased homeworking. As such businesses are not randomly distributed in cities, this will change the number of workers working in a particular location, but the exact nature of the change will depend on the land market responses. There will also be responses in the consumer services market to this change. This is because consumer service businesses follow the location of workers as they shift work locations.

Research need: To understand the potential impacts of homeworking on the employment component of ATEM (E_j). Such research could be undertaken by mapping potential land use change by industry, profession and location, taking into account the different propensities for different industries and occupations to homework. Given the agglomeration angle the analysis should map onto DfT's four industrial categories (construction, manufacturing, consumer services and producer services). A number of potential and inter-related work from home, land use and transport cost scenarios can be envisaged. It is important that any scenarios developed have consistency between these key elements: homeworking levels, land use change, transport cost changes.

Work from home potential scenarios: early research on the potential for work from home, the evidence on homeworking during the pandemic and stated intentions regarding homeworking post-pandemic reviewed in Chapter 2 indicates that in the UK approximately 40 to 50% of the workforce could work from home. During the pandemic these workers have in the main been working from home, and survey work has indicated that the vast majority wish to maintain some form of homeworking, though only a small proportion wish to work continuously at home. These data could act as upper bounds on any scenario analysis being undertaken. Other scenario analysis could be constructed from the empirical work identified in Chapter 2. For example the most popular option is that workers would homework 2 or 3 days a week. Thus an alternative scenario would be that only 20 to 25% of the workforce homework on any particular day.

Transport and land use change scenarios: a variety of transport and land use scenarios can be envisaged and as reviewed in Chapter 2 quite a number of authors have speculated as to the future. What ultimately happens will be dependent not only on a set of contrasting and opposing market forces within the transport and land markets, but also what role government plays in helping shape the future. If reductions in public transport service provision fall due to a lack of commuters then this would make the city centres more inaccessible exacerbating centrifugal forces on land uses

within the city. Contrastingly reductions in road traffic demand may ease congestion and make city centres more accessible. Which dominates for a city will clearly be context dependent. London with its high public transport patronage maybe more at risk from a collapse in the public transport system than some of the other UK cities. The role of government transport policy here is very important. In the land market the expected reductions in the demand for city centre office space will lower land rents, as businesses seek to downsize their workspaces in city centres. This lowering in rents will make the city centre more attractive to businesses that had previously been crowded out by high rents – thereby leading to an increase in demand for city centre locations. Such an increase in demand will mitigate some of the potential outflow of workers from city centres, but can for the most productive locations lead net job increases despite an increase of homeworking (see for example Delventhal et al. (2021) and Delventhal and Parkhomenko (2020)). The outcome of course comes down to the balance between the competing centrifugal and centripetal forces on land use within the city. Two extreme transport and land use scenarios for the calculation of agglomeration changes could therefore be:

- City centre workplace sizes remain fixed in size, but workers only travel in on 2 or 3 days a week. Consumer services shift location following workers. Public transport services contract accordingly, de-congestion benefits are experienced on the road network.
- City centre workplace sizes reduce, and spare city centre office space is taken up by firms located in the suburban fringe. The number of workers working in the city centre increase, albeit they do not all travel in to work on the same day. Consumer services shift location following workers. Public transport and road traffic conditions to city centres remain unchanged.

Research strategy: an empirical ex post research strategy will not be possible for many years. This research would therefore need to be conducted either using stated intentions, modelling based on geographic location (e.g. De Fraja et al. (2020)) , or more sophisticated accessibility and land use models including general equilibrium models (e.g. Delventhal et al. (2021)).

Data: Whilst substantial data is already being collated on homeworking and attitudes to it, these data need to continue to be collected, ideally in a systematic way e.g. with collaboration from the ONS, and collated in a form that would be useful for subsequent economic analyses. Looking long term an empirical strategy based on ex post analysis requires a longitudinal dataset (ideally a panel dataset), and efforts at an early stage (ideally now) should be made in setting such a panel up.

4.3 Agglomeration parameters

We expect the impact of homeworking on agglomeration in aggregate to reflect the combined effect of homeworking on each of its micro-foundations. Table 4-1 to Table 4-3 set out our expectations on the direction of change to the absolute impact of agglomeration externalities on worker productivity and the marginal impact.

Looking at the sharing mechanisms in Table 4-1 these represent sharing between businesses. For businesses to be able to share they need to be proximate to one another, so we are primarily interested in business to business connectivity (B2B). Taking for example labour market sharing for risk. Homeworking will make the labour market pool bigger, and firms effectively become closer together for sharing labour risk ceteris paribus. This will give an

absolute increase in productivity. The marginal impact of change in economic mass is not likely to change – in terms of the elasticity. A doubling of economic mass for example doubles the size of the labour market pool, and there is no reason to expect the impact of this on productivity to differ between pre- and post-pandemic levels of homeworking. However, given the impact of homeworking is to widen the absolute size of the labour market, effectively bringing firms closer together this can be interpreted as a reduction in decay or as a reduction in B2B interaction costs (the world is flatter). Given travel costs are unlikely to change it is likely that the decay parameter will lower. Similar arguments can be set out for the other sharing mechanisms.

Turning to the matching mechanisms in Table 4-2. If we see homeworking as something that increases the size of the labour pool by alleviating the commuting constraint, then we would expect a positive productivity impact arising through improved quality and chances of matching. In terms of the marginal impact as distance matters less in determining the size of the labour market pool then agglomeration forces will attenuate more slowly with distance. However, as commuting cost is the constraint we would expect agglomeration forces to attenuate at the same rate with average commuting costs – the fall in average commuting costs widens the labour market and agglomeration effects reflect that widening. Here commuting costs would need to be the average weekly cost. Thus if on average a worker commuted in 50% of the time their average daily commute cost would be half of the commute cost of a single trip to their workplace. That is the matching effect can be captured through an accurate representation on commuting costs/constraints without any adjustment to the agglomeration parameters. However, this is only the case if ATEM includes a B2C mass variable sensitive to commuting costs.

The TAG formulation of ATEM is solely B2B. Conceptually we could see that a lowering of the decay parameter in such a function could give rise to a slower attenuation of agglomeration forces – thus picking up some of the matching effects arising through homeworking. However, in a B2B formulation the focus is on proximity between firms and not between households and firms, and in the decay parameter here is picking up the attenuation effect of businesses moving closer and further apart. It therefore does not specifically identify the relationship between households and businesses. Care would therefore be taken if the decay parameter on a B2B function was to be adjusted – particularly in the absence of any evidence.

In contrast the learning mechanisms in Table 4-3 are heavily dependent on the ability to interact. How important the frequency of face-to-face interactions are is uncertain. At the extreme if the ability to interact face-to-face all the time is very important and this is lost, this could lead to this learning channel to agglomeration being blocked or certainly substantially diminished. The agglomeration benefits arising from the learning mechanisms may therefore be substantially lowered under a homeworking scenario

Research needs and data: At this point in time there is a lack of empirical evidence to quantify the effect of homeworking on the decay or the agglomeration elasticity. Empirical work is therefore needed. The crux of any empirical strategy is the data with which the econometrics is undertaken. Ideally a longitudinal dataset is needed. Historically some successes estimating agglomeration elasticities have been had using labour force data in the Labour Force Survey and the Annual Survey of Hours and Earnings (see e.g. D'Costa et al. (2013) and (D'Costa and Overman, 2014)). Ensuring that these data continue to be collected and can be used to unpick homeworking changes (which may require additional questions to be included in the surveys), would seem an important first step in understanding

homeworking changes as they occur in the post-pandemic era. The existing agglomeration parameter estimates (Graham et al., 2009) are also now dated. The study does not make it clear the age of the data it is based on, but one would presume they date back to 2000 – making some of the data 20 years old. Re-visiting these estimates and addressing some of the issues about the formulation of the ATEM function with respect to generalised travel cost and the treatment of commuting, business and freight travel costs would seem a priority.

Agglomeration variable scenarios. In the absence of data specific to the individual micro-foundations it is hard to offer alternative scenarios for agglomeration elasticities. At one extreme learning effects could be taken to be zero, which could reduce the elasticities by 60%. Thus one scenario could have elasticities at 40% of their current values. This agglomeration variable scenario seems rather blunt, and possibly overly pessimistic. Further research could be undertaken to develop some alternative agglomeration variable scenarios. For example an examination of the propensity by different industries to permit homeworking could then be linked to the reduction in the learning effect. Those businesses that permit a lot of homeworking (e.g. the tech companies) may lose the benefit of learning effects, whilst those that do not permit any homeworking (e.g. the investment banks (BBC, 2021b)) could retain all the benefit. Such an analysis would give a more heterogenous impact by industry.

It is hard to offer anything quantitative for the decay parameter for a scenario analysis due to a lack of evidence. Further research could however be undertaken on changes in commuting patterns as an indication of changes in labour market size. This could then be used to give some indications of the potential range in decay parameter. Caution however would be needed in interpreting such research as the decay parameter is part of a B2B function and not a B2C function (which labour market size relates to) – and it is clear that B2B proximity is very important for certain industries (e.g. producer services). Thus for such industries it may well be that it is B2B proximity (and associated decay that is most important). Nonetheless such research could illustrate potential bounds for variation in the decay parameters.

TABLE 4-1: IMPACT OF HOMEWORKING ON SHARING MICRO-FOUNDATIONS

Micro-foundation (source: Duranton and Puga (2004))	Absolute impact on agglomeration related productivity due to homeworking:	Marginal impact of homeworking on the agglomeration externality[1]
Sharing indivisible goods and facilities.	Homeworking is likely to not always be a perfect substitute, as there is a need to be in the city to obtain this sharing benefit, which is typically associated with the provision of public infrastructure (water, sewage, transportation, telecommunications, energy). Shift to homeworking would therefore lower productivity, but for some cities the provision of public infrastructure maybe equally as good in large parts of the city – meaning that there will be a negligible change.	Elasticity of productivity is likely to lower, with largest reductions for industries for whom a substantial proportion of their costs relate to the sharing of indivisible goods that are external to the firm. Will vary with industrial sector as sharing of physical goods/facilities external to the firm varies by sector. For locations where there is equally good access to shared infrastructure there is likely to be no change.
Sharing the gains from variety. .	For physical goods/inputs homeworking is not likely to be a substitute, but for goods supplied virtually home working could be a substitute e.g. for business services. ATEM increases because of a slower decay of the agglomeration forces (distance matters less and the world gets flatter). In principle this should increase productivity, but this is not related to benefits from transport improvements.	Attenuation of agglomeration forces with distance decreases, which could be interpreted as a lowering of the decay parameter. Variable impact by industry in addition to variations due to homeworking.
Sharing gains from individual specialisation..	Possibly the impact of homeworking could be negative here, as in some cases homeworkers may have to multi-task as they do not have access to support services in quite the same way and need to upskill in areas outside of their core specialisation – e.g. they may need to provide their own IT support and do their personal administration.	Attenuation of agglomeration forces with distance decreases, which could be interpreted as a lowering of the decay parameter
Sharing risk.	Home-working increases the size of the labour market pool, as commuting restriction is lifted. Home-working positively affects productivity. This is also the effect that distance matters less than before and increases productivity.	Attenuation of agglomeration forces with distance decreases, , which could be interpreted as a lowering of the decay parameter.

Note 1: Marginal impact on agglomeration elasticity will vary by industrial sector as homeworking varies by industrial sector

TABLE 4-2: IMPACT OF HOMEWORKING ON MATCHING MICRO-FOUNDATIONS

Micro-foundation (source: Duranton and Puga (2004))	Absolute impact on agglomeration related productivity due to homeworking:	Marginal impact of homeworking on the agglomeration externality[1]
Improving quality of matches.	Homeworking can improve quality of the match, as homeworkers can be located further from the workplace thus increasing the effective size of the labour market. Productivity will increase.	Can be captured through an accurate representation on commuting costs/constraints, but only within a B2C ATEM function. Empirical estimates of an ATEM function based on B2B (as per TAG) would likely lead to lowering in the decay parameter.
Improving the chances of matching.	Homeworking can improve chances of matching, as homeworkers can be located further from the workplace thus increasing the effective size of the labour market. Productivity will increase.	As above.
Mitigating hold up problems through ease of matching.	Homeworking can improve mitigation by increasing size of labour market, but may make it more difficult for the firm to observe the workers behaviour it they work from home. Leads to arguments surrounding which workers will be allowed to homework.	As above.

Note 1: Marginal impact on agglomeration elasticity will vary by industrial sector as homeworking varies by industrial sector

TABLE 4-3: IMPACT OF HOMEWORKING ON LEARNING MICRO-FOUNDATIONS

Micro-foundation (source: Duranton and Puga (2004))	Absolute impact on agglomeration related productivity due to homeworking:	Marginal impact of homeworking on the agglomeration externality[1]
Knowledge generation.	This depends on how dependent creativity is on face-to-face interaction, and how many times a week those face-to-face interactions need to occur to be creative. Impact uncertain as there may exist thresholds of contact that need to be maintained to generate knowledge. It is likely that homeworking will reduce levels of contact and therefore is likely to lower knowledge generation, with in principle homeworking reducing to zero the benefits agglomerations have on knowledge generation.	Likely to lower the elasticity, but heavily dependent on the frequency of face-to-face interactions necessary for knowledge generation.
Knowledge diffusion.	As with knowledge generation, with the addition that learning effects appear most important for recent movers and the young. Therefore, we would expect reductions in productivity to be largest for recent movers – as learning effects tend to diminish over time.	As with knowledge generation, but with the caveat that marginal productivity reductions will be smallest for those based in the city for longest (as learning effects diminish over time).

Micro-foundation (source: Duranton and Puga (2004))	Absolute impact on agglomeration related productivity due to homeworking:	Marginal impact of homeworking on the agglomeration externality[1]
	Firms may counterbalance this be requiring homeworkers to be based in the office early in their job tenure (see for example Battiston et al. (2020) and Choudhury et al. (2020)).	
Knowledge accumulation.	This is dependent on where the knowledge resides. In the workers? Or in the firms, the institutions and their processes and procedures? It is likely to be both, and as both are located in the city then possibly homeworking will be neutral, but possibly through a widening of the labour market pool it could be slightly positive.	Possibly neutral

Note 1: Marginal impact on agglomeration elasticity will vary by industrial sector as homeworking varies by industrial sector

4.4 Agglomeration benefits and TAG

Research need. At the nub of the motivation by DfT to consider the impact of homeworking on agglomeration is the impact on transport appraisals of changes in agglomeration, and whether changes in homeworking materially affect agglomeration benefits.

To understand this it would therefore be useful to identify how the propensity to homework, land use and transport costs scenarios (from Section 4.2) and the agglomeration parameter scenarios (from Section 4.3) impact on agglomeration benefits. Undertaking a switching values type of analysis on the size of the shifts in the agglomeration parameters and/or changes in land uses to determine the level of change needed at which the changes in agglomeration benefit become material would also be useful. The impacts on the cost benefit analysis are likely to differ with context. This is because the relevance of agglomeration benefits varies with context, for example: city centre projects, urban fringe projects, and inter-urban projects.

The outcome of such research would then help prioritise any future research in the field vis a vis other research DfT is considering. This is because the research may identify that there is a need (from a transport appraisal perspective) to research both changes in the agglomeration elasticity and the decay parameter, or that the biggest impacts on benefits stem from changes in the elasticity. It may similarly identify the impact of changes in land use on agglomeration is not as important as may have been thought, or only important for certain projects.

There is also the need to consider whether there is a need to re-visit the inclusion of commuting costs in the appraisal based on an increase in homeworking. At the moment in TAG commuting costs form part of the average generalised transport cost between zones (GTC_{ij}) in the ATEM calculation. Should it be the case though that average daily commuting costs should be used? Thus workers who commute only two or three times a week have a weekly average calculated. This also has implications with other parts of TAG – namely the labour supply wider impact whose model pivots on changes in commuting costs, and move to more/less productive jobs, where it may be the case that the job moves between regions, but the homeworker does not move location. Clearly

there will be variation by industrial sector, because as we have seen the propensity to homework varies by industrial sector and job type.

The key implications for TAG are in the parameterisation of the agglomeration formulae, and the treatment of commuting costs in the agglomeration model and in the labour supply model. Additionally There are inter-related questions on land use scenarios with different levels of homeworking. This is a broader topic and interfaces with other sections of DfT's analytical team who have custodianship of the treatment of uncertainty and the trip end growth model (TEMPRO) – which itself is driven by an agreed set of land uses.

The research associated with this thinkpiece has also identified an inconsistency in the manner that the ATEM function is defined in TAG. The form of the TAG ATEM function, including the averaging of generalised transport costs, is one based on judgement and not empirics. The agglomeration elasticities used in TAG are derived from a crow-fly distance decay function (see Graham et al. (2009)). TAG however defines it as a decay function in GTC, for obvious reasons of transport policy applicability. This however has led to a judgemental rather empirical derivation of the ATEM function used in TAG. In TAG the judgement was that accessibility in the ATEM is a function of business and commuting costs. On the face of it this seems sensible, but the inconsistency arises as the TAG ATEM function is B2B. The commuting costs therefore that are input to this function are the 'commuting' costs between firms (B2B) and not between households and firms (B2C). Freight costs are excluded in TAG, which clearly is inconsistent with business to business linkages. The literature would suggest that a B2B ATEM function should be specified as business and freight costs only between businesses. Extending the logic of that would imply that there is no place in the B2B function for commuting costs, and that changes in homeworking would not impact on ATEM, aside through changing employment levels in each zone. The issue arises from the empirical problems that make it difficult to specify ATEM a joint function of B2B and B2C. It will only be through new empirical research that specifically examines the form of ATEM within the agglomeration productivity econometric specification that the contributions of commuting, business and freight transport costs can be evidenced.[8] This line of work empirical work though may prove problematic though due to noted issues of collinearity between these different trip purpose costs.

4.5 Summary of Research Needs

We have outlined a number of research needs. Giving the age of the current agglomeration parameters (agglomeration elasticity and decay parameter) and the lack of evidence behind the formulation of the ATEM function this would strike us as the most important aspect of research to pursue. In the short term this could be undertaken using wage data. If looking to incorporate homeworking aspects into the empirical analysis the LFS is likely to be one of if not the best data source for such an empirical piece of work. Ensuring that the LFS collects sufficient data going forward to allow homeworking impacts to be assessed is clearly critical to future studies.

In terms of answering the question as to what the potential impact of homeworking will be on agglomeration benefits, this is clearly something that can explored in the short term using scenario

[8] TAG also specifies that agglomeration calculations should be undertaken at the local authority district level. Aside from London most commuting would be expected to be intra-local authority. This again reduces the role of commuting in the TAG calculation of agglomeration impacts.

analysis. It is likely to vary by the type of transport scheme. This should also have a high priority as it is likely to impact on the project benefit uncertainty of transport investments the DfT is currently considering. Here consistent land use, transport cost and homeworking scenarios will need to be constructed. The homeworking scenarios can be based on data from any of the many surveys on attitudes to homeworking that seem to be being undertaken at the moment in addition to the LFS. We have identified some data sources in Chapter 2. In chapter 4 we have also suggested some potential scenarios both for changes in transport costs and land uses, but also for the agglomeration parameters. The outcome of this research will then no doubt influence the priorities for future research – e.g. on land use modelling or on better agglomeration parameter estimates or on both.

Longer term a deeper consideration will need to be given to consistency across the different wider impacts in TAG such as labour supply effects – where the labour supply model is driven by changes in commuting costs which will be significantly impacted by homeworking – and move to more/less productive jobs, where it may be the case that the job moves between regions, but the homeworking individual does not move residential location. There is also the need to link between other parts of the DfT analytical strategy with regard to land uses (e.g. the land use inputs to the National Transport Model and TEMPRO) and to the treatment of uncertainty (in future land uses and homeworking propensity).

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