The Impact of Lockdowns on Mobility in City Systems

Roberto Murcio, Michael Batty, Richard Milton

Abstract: The current pandemic is a fast moving sequence of events structured around the rate at which human populations become infected through social contact. We chart the pandemic in the UK, showing how the first wave (April 2020) was flattened by lockdown through social distancing and working from home. The pandemic reasserted itself in a second wave morphing into a third in December 2020. We examine trajectories relating to how mobility is suppressed by working from home, social distancing, and household mixing. Lastly we explore how key workers commute between different tiers, testing the resilience of the lockdown to spatial interactions.

Keywords: **COVID-19 pandemic, trajectories of infection, lockdown, mobility**. [max 3]

JEL classification: C31, J61, I12.

1. The evolution of the pandemic in the UK

The rapid emergence of a new infectious disease of pandemic proportions took the world by surprise in the early months of 2020. We now know it as a particularly severe form of the «coronavirus» which has been called COVID-19. There had been nothing on this scale since the Spanish flu pandemic at the end of the first world war in 1918 which led to many more people perishing than in the war itself, by some estimates over 50 million persons, with perhaps one third of the world's population (more than 500 million) then being infected. Since the 1918 pandemic, the world has grown massively more connected with the potential for increasingly fast transmission of viruses and although the wider informed public has some sense of the dilemma that ever more global transportation can generate ever more rapid spread of disease, no one was prepared for the crisis that began in

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early 2020. Few had any real experience of pandemics and two of its most significant characteristics were its rapid spread and the high frequency at which the scale of its spread – its impact on human populations – could change «upwards» or «downwards» over a matter of days (as we observe from many COVID-19 cases trackers worldwide[1]). This of course is in the nature of exponential growth where its takes a matter of days for a person to show the infection and the lag between being infected and becoming unwell is long enough to confound any precision in figuring out who infects who.

In previous plagues which have dominated our entire evolution, keeping away from the source of the disease is the time-honoured strategy based on common sense reactions. The basic dilemma however that mankind has to confront is that infections can be caused either by ourselves infecting others through respiratory and other bodily means or from being exposed to other animals who pass on the plague to human beings. Historically in the absence of knowing the source of infection, we assume that we need to keep apart from those who have clearly contracted it. The term social distancing began to be used in the 1920s at the Centers for Disease Control and Prevention, but it appears as a mechanism in various sociologies that pertain to how different groups keep themselves apart for cultural reasons. It was not until the SARS epidemic in 2003 that it moved into the common currency that we now use and in fact, there are many groups who consider the proper term should be «physical distancing» as much as to assuage any social connotations. Currently the rule to maximise safety which has been adopted by most public health agencies is physically to keep at least two arms' length, 6 feet, or 2 metres apart from one another (Batty, 2020).

As well as social distancing to reduce the transmission of the virus, the wearing of masks to contain respiratory movement, the donning of personal protective equipment, and the washing of hands, various physical limits have been established with respect to where and for what purposes people can meet and interact. In Britain, a national lockdown was imposed as soon as it became clear that a pandemic was about to engulf the world. On March 23rd, the population was urged to work from home, only key workers were allowed to travel to work, non-essential shops were closed with only food and related outlets remaining open and even there strict physical distancing was imposed. Households were not allowed to mix and only essential exercise was allowed. This lockdown lasted for some 3 months, until June 21st, the summer solstice, and then the restrictions were gradually eased as it was clear the virus had been contained and demand on the health services for treatment of illnesses associated with the virus fell quite rapidly. The clear issue in this first phase and this has continued to be the focus, was the ability of the health care system to cope with increased numbers of

[1] https://coronavirus.jhu.edu/map.html; https://coronavirus.data.gov.uk/details/cases; https://covid19.who.int/region/euro/country/it.

severely ill COVID-19 patients which threatened to overwhelm the system. New hospitals were brought on stream but severe limits on the number of available health care workers represented a massive constraint on the capacity of the system to respond. But the first wave was contained and by late July, there appeared to be some semblance of relief.

The warning of a second wave once people relaxed their stance was mooted almost as soon as the pandemic took off, well before the first wave had played itself out. By late September, it was evident that a second wave had begun and the government began to impose various restrictions, introducing a 3-tier system with different levels of restrictions from the lowest (Tier 1) to the most severe (Tier 3) on October 12th. There was considerable variation in local conditions during this period although there was clear evidence of the second wave being contained – «flattened» in the jargon – but a new milder form of lockdown was imposed on 5th November, notwithstanding that several areas in the larger northern cities had been subject to local restrictions for over a month. The second lockdown came off in early December but by then infections where rising again and a new harsher 3-tier system was introduced on December 2nd. There was by then clear evidence of a third wave emerging. This now appears to be as much due to the emergence of a mutation of the virus that is up to 70% faster with respect to its transmission, and although it appears that this mutant or variant does not lead to a step change in the severity of the illness, it is much more virulent. At the time of writing (31st December 2020), the situation is again critical with the health service being overwhelmed with new cases and the number of excess deaths due to the virus rising to about 400 each day. Most of the country is now locked down with new Tier 4 rules that forbid travel between different tiers, the closure of all retail outlets except essential shops, schools currently closed, and very limited household mixing. The picture is a little confused with respect to the different layers of lockdown particularly as the devolved governments in Northern Ireland, Scotland and Wales have their own variants of these rules. But in essence, the country is now in the third lockdown with little prospect of this ending in the immediate future[2].

We organise the rest of this paper as follows: first, we review the pandemic's impact on the UK's economic activities and urban mobility, using the Gross Value Added as a proxy for the former, and the Google Mobility Reports for the latter. We then look into the government's tier system introduced in early December 2020. We examine its impact on the mobility of key workers, and then we conclude presenting a what-if scenario where we explore the consequences of limiting the mobility of non-key workers among tiers.

[2] By the time of the first review of this paper (26th March 2021) England had exited from the third lockdown in a sequence of escalated steps, with the aim of ending the restrictions by July 26th 2021. This figure is by no means firm as at the time of revision of this paper (18th May 2021), there is the growing threat of a fourth wave from the Indian variant of the virus.

2. The impact of the pandemic

The best way to visualise the course of the pandemic is to plot deaths, hospital admissions, and the number of infections which is what the government does in its daily briefings. In Figure 1, we show the key statistics which define the evolution of the pandemic as it applies to the United Kingdom (which includes the four constituent countries of England, Scotland, Wales and Northern Ireland) (PHE, 2020). These figures show the three waves. In terms of deaths in Figure 1*a*, the first wave is a classic exponential rise and fall with the second and third waves being more convoluted, clearly dependent on the new strain of the virus which has emerged in the last three months of the year as well as complex and constantly changing lockdowns of various severities. The admissions to hospitals represent a much clearer picture of these waves in Figure 1*b* although this only covers the most severely ill. The infections data in Figure 1*c* is more complex in that it depends on the number of tests for the infection that are administered and it took several months in the UK for the testing system to be developed. There is still only a rudimentary set of procedures for track and trace. As in the entire experience of dealing with the pandemic, much of this is based on «learning-on-the-job» so-to-speak, and it will only be in the hindsight after the pandemic ends that we will be able to produce a more coherent picture of the various waves and the success or otherwise of different lockdowns.

There are two other easily accessible indicators of the pandemic. Various economic agencies and government have tracked the economic performance of the economy that has almost closed down and continues to largely only tick over in terms of the provision of essential services. Most entertainment, retailing, school-level education, and public transport are only operating at the most basic levels. Gross Value Added (GVA), quite a good measure to record economic activity, has plummeted (ONS, 2020a). In Figure 2, we show the long term value of this index over the last 25 years. The economic data is not as up-to-date as our mortality, infections, and hospital admissions data or the mobility data that we introduce below from Google. This is because the measurement of these data needs to be assembled from many diverse sources that do not report on daily or even weekly cycles. The data up to October 2020 show a massive drop – something in the order of 20% from the peak value of February 2020 to the nadir in June 2020 with a subsequent recovery but certainly not back to pre-pandemic levels. In October 2020, GVA was still more than 10% below the optimum and after this, the second and third waves have kicked in. All we have are informed speculations such as those made by the National Institute of Economic and Social Research (NIESR, 2020) and the Office of Budget Responsibility (OBR, 2020) whose various scenarios for the immediate and near term future suggest that a limited form of recovery could take place by the end of 2021. This, they suggest, is problematic while the worst case scenarios suggest that recovery

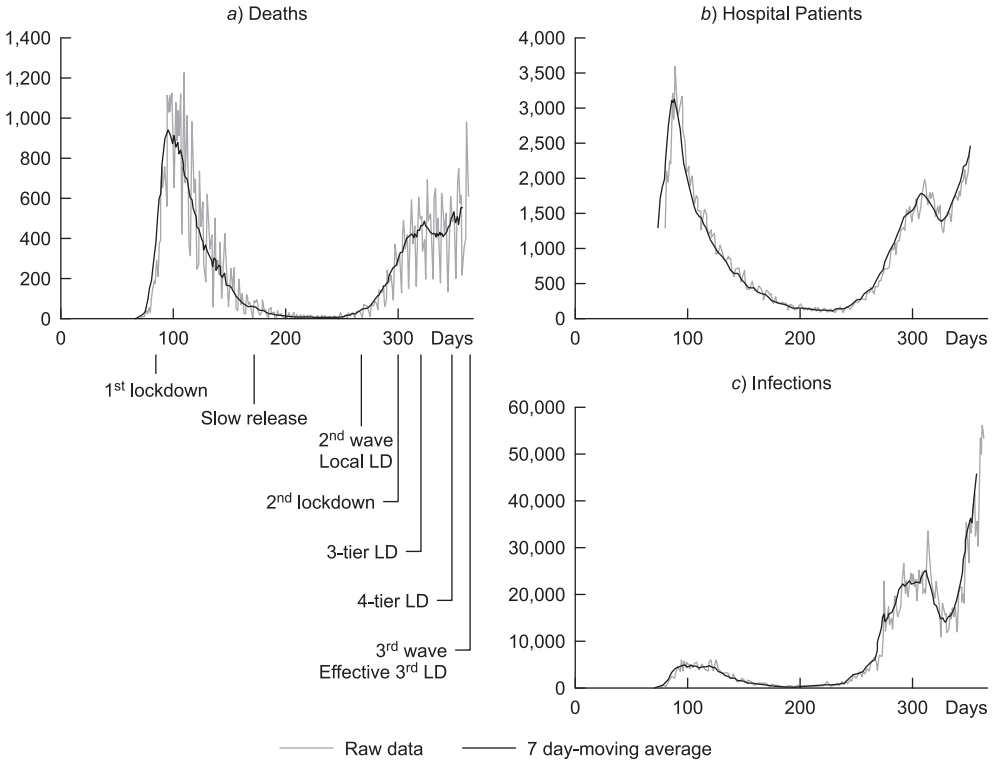


Figure 1: The progress of the pandemic in the UK: *a*) Deaths, *b*) Hospital Admissions, and *c*) Infections in the year 2020.
Source: https://coronavirus.data.gov.uk/.

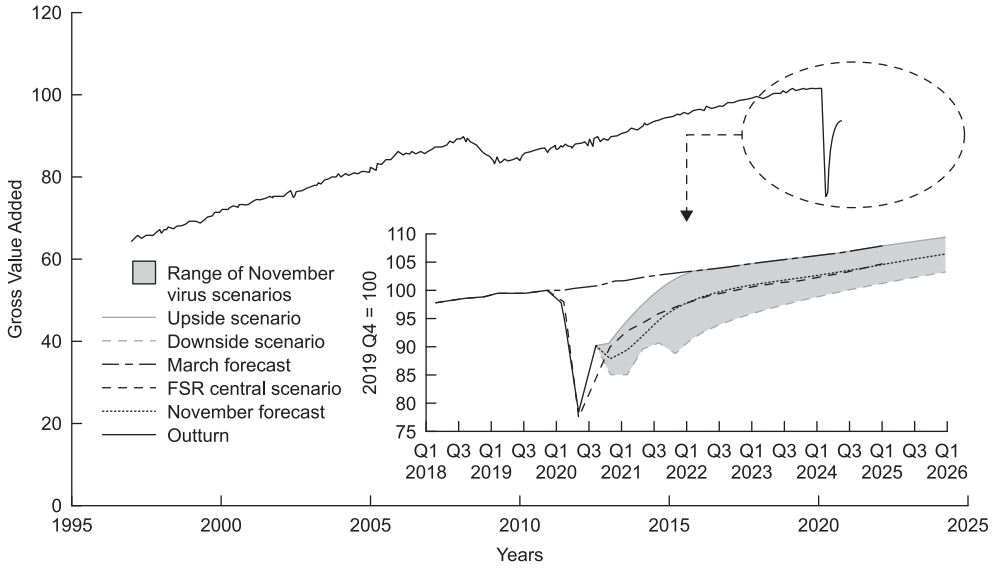


Figure 2: Gross Value Added from 1995 to 2020 from ONS (2020). Inset: Predictions from the OBR (2020).
Source: ONS (2020) and OBR (2020).

could be as late as 2024 or even 2025 before the economy is restored to pre-pandemic levels (MacQueen, 2020). In fact, current events suggest that even this might be over optimistic. Much depends on confidence which will, of course, be massively restored once the pandemic ends but what permanent damage will have been done is difficult to forecast.

The last set of national indicators of the impact relate to the core focus of this paper – questions of how the pandemic has changed mobility. Google Mobility Reports (2020) provide a very clear time series on a daily basis of the volume of activity monitored by Google from use of their sites. They release this data for many different locations. In the case of the UK where there are several tiers of authority, areas chosen are those local authority areas aggregated to the key service providers which number 410. The data is based on capturing location from mobile phones where the user has location-finding switched on for Google services and in this sense, like all real time streamed data from personal devices, it is limited to those who have such devices and software which although substantial is nowhere near complete. It would appear however that given the volumes of users involved, the data is strongly indicative of the more general picture.

In these reports, six key activities are identified and measured with respect to the percentage change from the baseline – set as February 5th, 2002. These provide different measures of displacement which we can attribute largely to the pandemic although there may still be other factors that change occupancies and capacities, such as in the case of the UK, leaving the European Union (Brexit). The six activities are as follows: (1) usage of retail and recreational facilities, (2) patronage of grocery and pharmacy outlets, (3) use of parks, (4) volume of travellers using transit stations, (5) those attending their workplaces, and (6) those domiciled in various ways at home in residential accommodation. For grocery and park usage, the activities have varied somewhat less than the other four in that successive lockdowns have inhibited use of these activities but for the most part there has been increased use and patronage due to the need for exercise and essential goods. In all other cases, there was a massive decrease in activity down to 80% of normal levels and then a gradual recovery during the summer, with great volatility over the last 6 months as the second and third waves have kicked in. The graphs shown in Figure 3 reveal these patterns and it is worth looking at each one of these for they do indicate how sensitive activity use is with respect to different lockdown policies.

The trajectories of transit usage in Figure 3*b* and workplace occupancy in Figure 3*c* are the most stable with a big drop to about 80% below normal levels in March 2020 in the first lockdown rising back to about 25% below normal in the workplace by the midsummer but rising only to 40% below the normal for transit usage. But then the second lockdown sharply reduces both activities with a change back towards the old normal in early December and then a massive plummeting down back to nearly 90% below

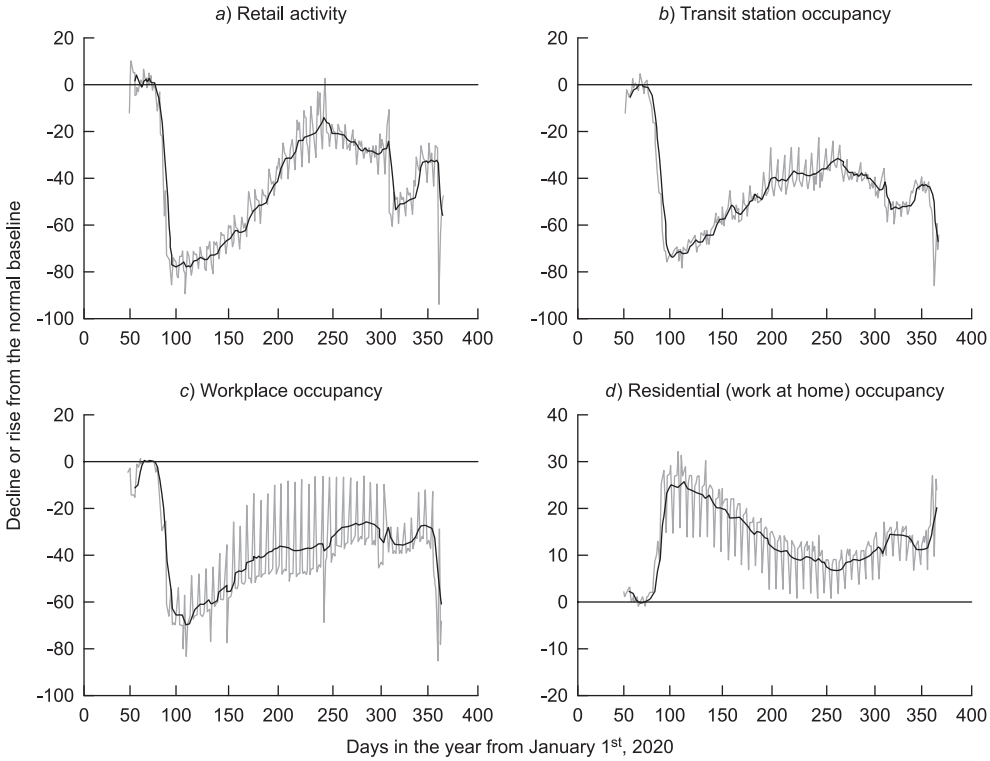
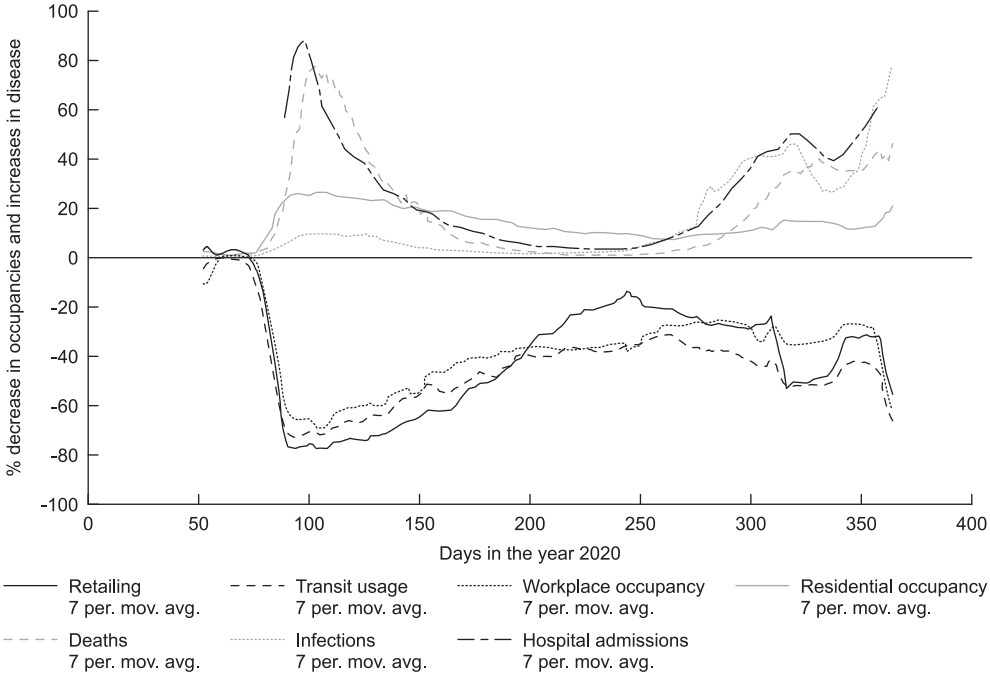


Figure 3: Retail occupancy, mobility through transit, workplace, and residential occupancy during 2020.
Source: Google Mobility Reports (https://www.gstatic.com/covid19/mobility/Region_Mobility_Report_CSVs.zip).

normal transit at Christmas and New Year. Retail activity follows the same pattern except that the rise back is faster in the summer months but then the second lockdown due to the severe tiering system shows up quite clearly with retailing also plummeting at the end of the year. In an opposite way, if people do not travel to work, they work at home and Figure 3*d* shows that levels of residential use increase to 30% above normal during the first lockdown, remaining at 10% above normal in the summer and then following the waves and lockdowns at the end of the year. Currently (early January 2021) the drop in employment, transit use and in retailing is as severe as it has been throughout the entire pandemic.

In Figures 1 and 3, it is clear that we need to use an averaging to get rid of the cyclical changes due to change from weekdays and weekends and this is shown by the seven day (weekly) moving averages. It is particularly important in Figure 3. In fact to conclude our brief foray into the quantitative impacts of the pandemic on location, insofar as we have the data yet to explore this, it is clear the profiles are highly correlated with one another. We can in fact array the three epidemiological factors in terms of deaths, infections and hospitalisations against the four activity profiles for retailing,



Ret	Transit	Work	Res	Deaths	Hosp	Infects
+1.00						
+0.89	+1.00					
+0.65	+0.84	+1.00				
-0.77	-0.88	-0.94	+1.00			
-0.60	-0.64	-0.40	+0.58	+1.00		
-0.51	-0.66	-0.33	+0.51	+0.83	+1.00	
-0.05	-0.22	-0.04	+0.09	+0.40	+0.53	+1.00

Figure 4: A composite of the mobility and disease vectors and their impact on daily activity.
Note: Note that the vectors of disease: deaths, infections and hospitalisation have been normalised to the maximum over the year 2020. The correlations between all these disease and mobility vectors are given in the matrix below. Detailed trajectories for each of these vectors are in Figures 1-3.
Source: ???.

transit usage, workplace occupancy, and residential usage. We do not have the detailed data yet to be able to add economic measures to this but the correlation matrix based on data from March 23rd to December 29th 2020 is shown in Figure 4 alongside the seven trajectories which are overlayed on one another.

As you might expect, the correlations between the mobility data – retailing, transit, workplace, and residential occupancy are quite high and simply reinforce the fact that retailing and transit, and transit and workplace explain over 80 percent of the variance. The cluster of disease data shows deaths

lagging behind hospital admissions but the correlations between these are quite high while the infections data shows less correlation with deaths and hospitalisation largely because this data is so dependent on the ramping up of testing during the pandemic. All of this analysis could be accomplished at small area level and we have explored some of this with respect to the way key workers differ from non-key in terms of their mobility (Batty *et al.*, 2020). In the rest of this paper, we will present some of this more detailed analysis but it is important to emphasise that there are many different dimensions to the pandemic and all we can do here in terms of a spatial focus is introduce a perspective which needs to be taken forward and elaborated once the pandemic is over, thus enriching our understanding of how epidemiological processes affect the evolution of city systems and change the basis of mobility in cities (Batty, 2001). This is as much for knowing how to do deal with future pandemics as well as developing new insights into how we react to crises posed by the emergence of such unusual, surprising and unpredictable events.

3. The second lockdown and the introduction of the tier system

The entire pandemic so far has resulted in many thousands of workers no longer working at their usual place of work as well as many children being schooled at home and many no longer engaging in entertainment, shopping and other cultural pursuits outside the home. This has had enormous effects on mobility as the data plotted above demonstrates, but the effects are nowhere uniform, particularly in the last 6 months of the pandemic. Since the summer of 2020, differential lockdowns have replaced the national lockdown and different authorities have imposed their own restrictions on mobility. As a backcloth to this picture, the government at the start of the pandemic introduced a distinction between key and non-key workers with non-key being assumed to «work from home» and key still being located at their place of work. In fact it would appear that there is some license to this distinction in that even within the key category there has been a good deal of discretion with respect to whether or not the worker visits their traditional place of work. In fact as a rule of thumb, about 22% of workers are classed as key, the rest non-key as defined by the Institute of Fiscal Studies (Farquharson *et al.*, 2020).

One of the main issues in exploring the geography of lockdown is how many workers move between tiers. After the second lockdown which ran from 5th November to 2nd December, this was replaced by a 3-tier system with the lowest tier being the least restrictive but with only the most remote authorities within it and then the rest of England divided into Tiers 2 and 3 of increasing severity. It is this lockdown that we will focus on here because

this is the most spatially differentiated particularly between the north and the south of the country. We should also qualify our analysis at this point because although we have been dealing with the UK, the four devolved national governments – England, Scotland, Wales and Northern Ireland all have their own systems of lockdown, Wales and Northern Ireland being treated as entire units but with England and Scotland separated into their constituent local authorities. In this context we will only study the tier system that was introduced to England after the second English lockdown in November. What we really require of course is a complete analysis of all elements of the lockdown of various types during the course of the pandemic over the UK and possibly Ireland) so we can get a much better overall picture of what is a confusing set of changing restrictions. This will only be possible in a post hoc analysis of the pandemic which is many months away as yet but we should also note that the 3-tier English system was evolved to a four Tier system on December 19th with many authorities moving into 4-tier which is even more restrictive. At the time of writing, a new English lockdown of the same level of severity as the first wave lockdown has been introduced (January 4th, 2021). Given so many differences, the patterns of commuting for key workers and the variable restrictions on non-key workers make it currently impossible to get a clear picture of the economic impact of these variations as well as the extent to which the virus is spread by these patterns.

The 3-tier system (Govt, 2020a) for England is shown in Figure 5 with these tiers being based on varying levels of infection across the country with the three tiers being defined as Tier 1 (Medium Alert), Tier 2 (High Alert) and Tier 3 (Very High Alert). As we noted above an additional tier was introduced in late December and the majority of the English population (78%) where then located in Tier 4 areas. Each tier had a particular set rules for business to remain open (Govt, 2020b), but in general, most businesses and venues could open under Tiers 1 and 2, given that they followed the COVID-19 secure guidelines with schools, universities, colleges and early year nursery education also being allowed to open in all tiers. However, the advice of working from home when possible remains and travelling between tiers was not encouraged. As we will show later, these two restrictions have an important impact in the commute dynamic of local areas. The hospitality industry is one of the most affected sectors under the tier restrictions, as these venues need to operate reduced hours, and in Tier 3, public houses and bars can only operate on a takeaway basis, with the corresponding impact on the number of employees they require to function translating into less commuting trips to certain areas. Figure 1 shows the geographical distribution of the three tiers at Middle-layer Super Output Areas (MSOAs) level (Govt, 2020c). In England there is total of 6,791 MSOAs and from those, only 88 (1.2%) are in Tier 1, 3,822 (56.2%) are in Tier 2 and 2,881 (42.4%) are in Tier 3. At September 2020, England had a working population of around 27.5 million, with 99% of them in Tier 2 or 3 (58% and 41% respectively).

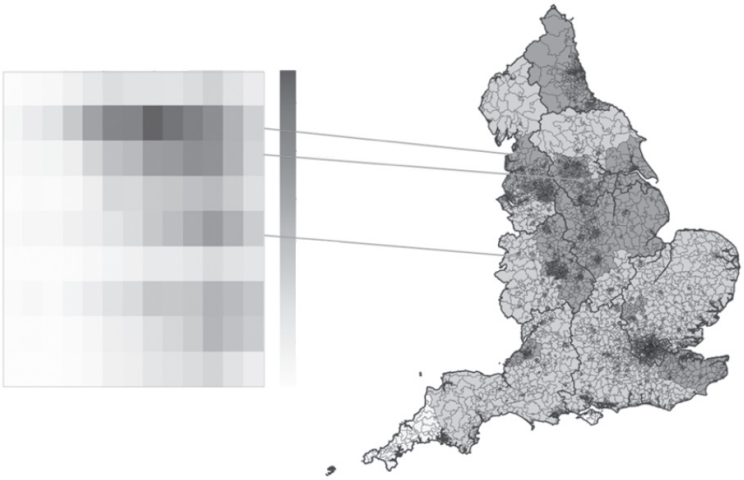


Figure 5: Weekly changes in COVID-19 infections at 27th November at MSOA level and its corresponding geographical position under the 3-tier strategy.
Source: ???.

Pairing these figures with the official COVID-19 cases from September to November 2020, the rationale for putting most of the North West and Yorkshire in Tier 3 for example and why London and most of the East Midlands are in Tier 2 is explicable, as is clear from Figure 5.

In the rest of this paper, we will illustrate the impact of England's tier system on commuting patterns and how some areas are highly dependent on their neighbourhoods' working population while others operate in a more self-sufficient manner. Taking London as an example, and by analysing the location patterns of key and non-key workers (defined in terms of their type of occupation), we will see how financial centres like The City and Canary Wharf (in Tier 2) are practically unaffected by the lack of working trips from Tiers 1 and 3, but show a decrease in trips when only key workers from certain occupations are travelling.

4. Key workers and commuting between tiers

During the first lockdown, and to help those workers whose activities were required to keep the country running, the UK government outlined (Govt, 2020d) a series of «key» occupations who were entitled to send their children to school. We matched this list with the Standard Occupational Classification 2010 (SOC) and with the Annual Population Survey for the Regions by employment type, both published by the Office of National Statistics (ONS, 2020b). The list of such occupations and their classification into key and non-key are shown in Table 1.

Table 1: Percentage of key workers by occupation in England.

Occupations	Employment	Key Workers	% Key Workers
1. Managers, directors and senior officials	389,100	18,500	5.55
2. Professional occupations	835,800	212,500	22.11
3. Associate professional & technical occupations	568,600	162,400	23.48
4. Administrative and secretarial occupations	381,900	68,100	13.30
5. Skilled trades occupations	467,300	108,000	21.13
6. Caring, leisure & other service occupations	409,200	139,200	30.53
7. Sales and customer service occupations	351,300	16,700	4.91
8. Process, plant and machine operatives	265,200	114,600	45.41
9. Elementary occupations	448,600	86,200	20.76

Note: Note that the percentages do not add to 1 in this table as they represent the proportion of workers from each occupation and not the proportion of the total.

Occupation 8, which is the one with the highest percentage of key workers, is where all food chain related occupations are classified; nurses and doctors are in occupation 2 while the vast majority of the people working from home are in occupations 1, 4 and 7. It is important to note that the occupation data is provided at regional level, while the tier and COVID-19 data is at MSOA level. Due to this restriction on the data, we have to use 2011 distributions which we can then scale up to these more recent totals. In this work, we will talk in terms of percentages of total employment at different spatial scales, thus removing the vexing problem of exactly how many workers there are from the most recent counts which do not break down in terms of the categories we adopt here. Hence the need to use distributions from 2011.

To explore the impact that the tier system would have on key/non-key workers' commuting patterns, we propose a what-if scenario, where only key workers are allowed to travel to work. In contrast, the rest of the working population works from home. We implemented this scenario using the QUANT spatial interaction model (Batty, Milton, 2021).

First, we have identified the key (k) and non-key workers (nk) into where they work $E_i(k)$ and $E_i(nk)$ and where they live $P_i(k)$ and $P_i(nk)$. We define these as follows, noting that the number of trips from an origin to a destination (MSOAs) for the relevant class of worker is $T_{ij}(k)$ from which

$$E_i(k) = \sum_j T_{ij}(k);\ E_i(nk) = \sum_j T_{ij}(nk);\ \text{and}\ E_i = E_i(k) + E_i(nk)$$

For the destination-residential end, the relevant populations are

$$P_j(k) = \Sigma_i T_{ji}(k);\ P_j(nk) = \Sigma_j T_{ji}(nk);\ \text{and}\ P_j = P_j(k) + P_j(nk)$$

From our data, key workers constitute 19% of the total. The list from the UK government as interpreted by the Institute of Fiscal Studies suggests that 22% of all employment is essential (Farquharson *et al.*, 2020) and this compares to our own estimates of 19%, the differences coming from different estimates of total employment, and the fact that Northern Ireland is not included in our analysis. We will not show the spatial distribution of $E_i(k)$, $E_i(nk)$, $P_i(k)$ and $P_i(nk)$ in terms of population density, largely because the patterns at the scale of England only reveal that these densities vary strongly with the extent and locations of the largest cities. There are two overwhelming impressions from mapping this data (Batty *et al.*, 2020). First, the employment distributions at the workplace are dominated by the sheer scale of jobs in the big cities, and when we factor into this the key and the non-key workers, these distributions are still dominated everywhere by the very high concentrations of employment in a very small number of locations. Second, the largest volumes of key workers are in the biggest employment locations even though they may vary dramatically in different parts of the country with respect to the composition of the different types of key occupations. The traditional travel to work commute has been severely disrupted during the different degrees of «locking down» in the UK. On the options for commuting, a new normal is emerging, confounding our traditional ideas about transport modes. Traffic jams are already building while new cycling improvements are taking place across cities (Batty, 2020).

The problem we seek to address here is to measure the effect of the tier restrictions over work related trips. As mentioned, people were advised not to travel between areas from different tiers (as they still are under the latest lockdown) and this translates into $P_j = 0$ for all T_{ji} where $j \in$ *tier x*, $i \in$ *tier y*, $x \neq y$. With these new restrictions, we recalculated the number of trips at the work end and obtained a new P_j'. To measure the actual impact, we calculated the difference in trips $P_j - P_j'$ which we show in Figure 6.

The first thing to notice is the evident correlation between the Tier 3 areas and their surrounding Tiers 1 and 2. The ring formed in the middle of the country follows the exact shape of the Tier 3 regions (see Figure 6*b*) and this denotes an important reduction of trips for the Liverpool-Warrington-Stoke-on-Trent-Birmingham corridor. In the north, the Yorkshire region is flanked by a large number of Tier 3 areas, and this has a negative effect on all the small towns (North Allerton, Boroughbridge, etc.) and on larger cities such as York and the towns north of Leeds.

For London, which we show in Figure 7, we can observe how the South East of the country is the most affected area when inter tier trips are cancelled. The effect of this restriction extends all the way to the city centre, although The City of London and surrounding areas do not lose more than 10% of their trips. The rest of London appears to be relatively self-contained in the

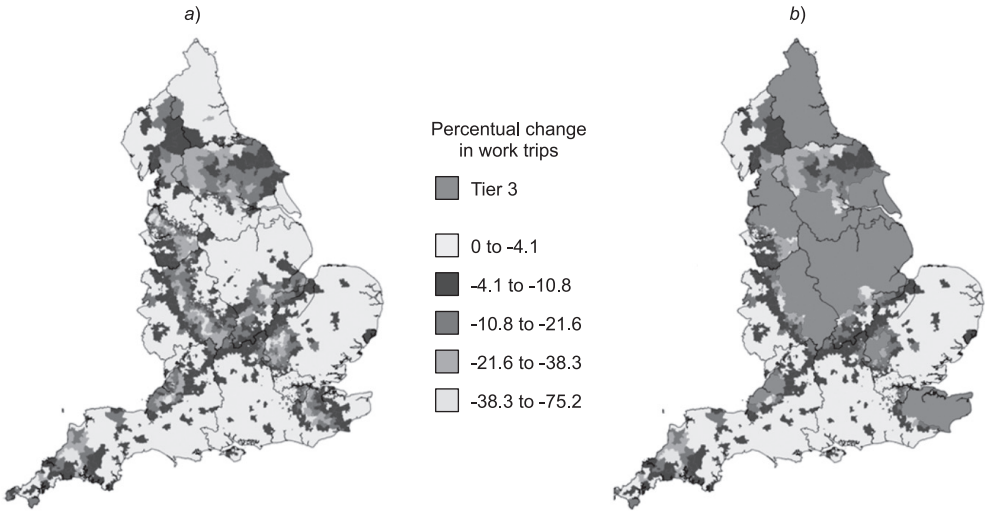


Figure 6: Difference in trips when no travel between tiers is enforced.
Note: *a*) The yellow areas are those strongly dependent on workers from other tiers. *b*) The same as a) but with the Tier 3 areas overlapping. We can observe the influence of Tier 3 areas over their nearest neighbourhoods, where higher percentual changes are registered.
Source: ???.

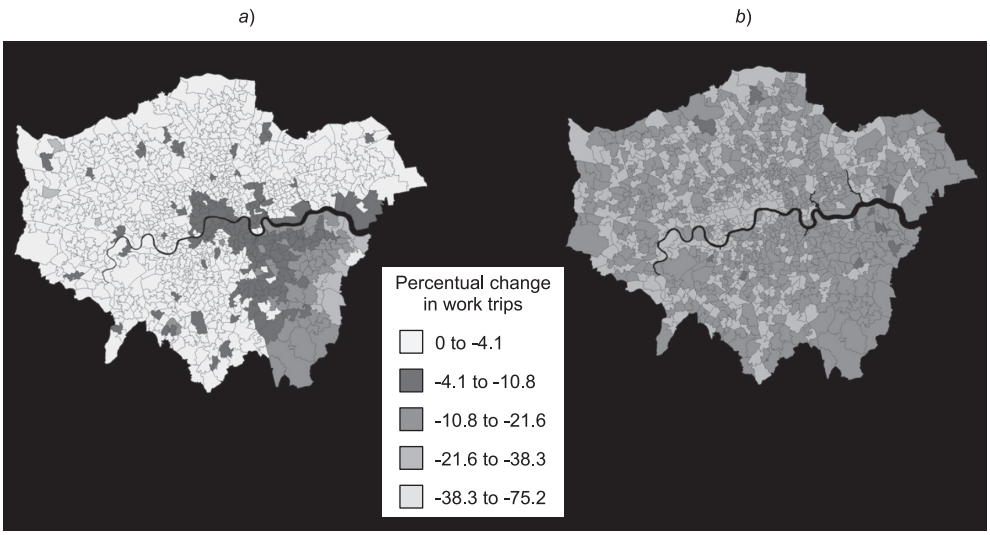


Figure 7: *a*) London when no inter tier trips are allowed *b*) London when non-key workers from occupations 1 and 4 are not travelling. The scale is the same for both maps to make them comparable.
Source: ???.

sense that all of their working trips come from areas in the same tier (Tier 2). Special mention in the area of Northwood (the north west area in Figure 7*a*) that exhibits a loss in trips of almost 40%, despite not being near to a Tier 1 or a Tier 3 neighbourhood. The City of London and Canary Wharf

are the two main financial centres in London. Both areas adjacent to Tier 3 area in south east London are not affected very much. Also, one of the largest employers in London is Heathrow Airport to the west, and all these areas are completely unaffected by the inter tier trip restrictions. In general, the city's core area loses no more that 10% of its work force, but the outer zones lose between 20% and 40%, and in some cases, more than 50% of their working trips.

During the pandemic, the advice from government has been that, where possible, people must work from home. This has been particularly true for workers in managerial positions and administrative roles. These two occupations correspond with Occupation O1 Managers, directors and senior officials and Occupation O4: administrative and secretarial occupations. In England, the key worker percentages for O1 and O4 are low at 5.5% and 13.3 respectively. If we assume that working trips only occur between the same tier areas, and from those where only key workers from occupations O1 and O4 are travelling, we get a different commuting pattern. As an example, Figure 7*b* is a complement to Figure 7*a*. Now, the areas where most trips are lost are in the west, instead of the east; the City and Canary Wharf have almost 30% less working trips. This is to be expected as most of the financial sector can carry on their activities remotely. On the other hand, Heathrow Airport still exhibits a marginal loss of trips (15%), which indicates that most of the jobs there are from other types of occupation.

5. Conclusions: a wider programme for understanding epidemics

Our spatial analysis of the pandemic is dominated by variations in the quality and availability of the data. It is hard other than in the most casual terms to relate the Google Mobility data to the issues of key workers commuting across different tiers. What we clearly require is a blow by blow account of how the key workers who are allowed to commute to work are affected by the definition of tiers. Strictly key workers should not travel across tier boundaries as this potentially spreads the virus from lowly to highly infected areas and vice versa. What we should be able to do with a better exploration and capture of data that does exist but is as yet uncoordinated is a timeline of how different geographical tiers have affected commuting patterns, noting of course that until the current lockdown which is across the nation, the variable lockdowns do provide opportunities for some to travel, that is, for workers who are not key to also commute to work if they so wish. It should be possible to produce a picture of how this balance has changed over the course of the epidemic. If we tag income data to this we can provide a picture of how the national space economy has fared with respect to people at work in their place of work. We might even be able to

compare this to those working from home and build up a picture of how the economy has fared differentially and geographically during the course of the pandemic.

What we urgently require is data that tells us much more about the consequent travel patterns as different degrees of lockdown are imposed and as people react in different ways. We also now need to map the distribution of the vaccine into this picture in that there is little doubt that this will affect the geographical spread of infections. In areas where there are high proportions of older people who will be vaccinated first or areas where there is a concentration of health workers, then it is entirely possible that it will have a major effect on the spread and containment of the pandemic. This will introduce another dimension to the pandemic which will be strongly spatial in its impact and there is the speculation that different geographical strategies for rollout of the vaccine related to age and other categories of the population will lead to differential reductions in the severity of the pandemic as well as differential restoration of parts of the economy. In short we need to extend our analysis to quantify the impacts on the national and local space economy and this is a challenge that should be foremost in extending this research further.

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