**Introduction**

The COVID-19 pandemic has rapidly changed our daily lives. People have been adapting to life with COVID-19 to mitigate the risk of infections. Greater reductions in mobility have been experienced since a wide array of social distancing measures were implemented, compliance with stay-at-home orders and other travel restrictions at the national level (Hale et al. 2021; Kishore et al. 2021). People must be aware of higher risks in face-to-face meetings, thus required to adapt to radical disruptions, such as an almost total ban on social gatherings, to prevent the spread of the virus as the outbreak evolves. The risk for COVID-19 infection has contributed to and will continue to influence people’s day-to-day lives, including travel behaviours. Various countermeasures have led to an increase in home-based activities, such as a shift from on-site work to remote working (Beck & Hensher 2020a; Budnitz & Tranos 2021), and a modal shift towards private transport and greater use of active modes, such as bicycling and walking (Hu et al. 2021a; Kim et al. 2021; Zhu et al. 2022).

Despite the challenges posed by the COVID-19 pandemic, it also offers new opportunities for researchers to explore mobility in pandemic times (Oliver et al. 2020). Many studies have focused on the short- and long-term effects of COVID-19 on travel behaviours using large mobile phone datasets (Xiong et al. 2020; Hong et al. 2020; Hu et al. 2021b). The evolution of mobility under nationwide lockdowns and strict quarantines were taking place in the first wave. These measures effectively tackled the spread of the virus and reduced COVID-19 infections and deaths before the vaccine was introduced (Haug et al. 2020; Ross et al. 2021). However, it has also led to several negative effects on the economy (Rose et al. 2023), and society, such as mental health problems (Mouratidis & Yiannakou 2022), while stay-at-home orders were extended to keep up with strong social gatherings.

In most existing studies, less attention has been paid to the exploration of the spatio-temporal developments of mobility in pandemic times. The first wave of the pandemic proposed quantification of four distinct phases based on the different magnitude of mobility reductions; original, disruptive, recovery, and new steady phases (Wang et al. 2022; Liu et al. 2023). A growing body of literature on the disruptive phase has focused on the effect of (nationwide) lockdown measures to uncover spatial variation of mobility reductions against the original phase. Extensive evidence has been found that overall levels of people’s mobility have dropped instantly against the pre-pandemic baseline, as seen through the lens of data-driven mobility metrics using large-scale mobile phone data (Enoch et al. 2021; Lee et al. 2021; Lucchini et al. 2021; Kim & Kwan 2021; Weill et al. 2020), and also through online panel survey data with GPS traces (Borkowski et al. 2020; Bohman et al. 2021; Molloy et al. 2020; 2021). Several studies have further been considered to demonstrate the uneven ability to restrict everyday mobilities among individuals. By examining reduced travel distances with shrunk activity spaces, it has been found that these differences vary greatly by region and are associated with inequalities in occupations and earnings (Chang et al. 2021; Glodeanu et al. 2021; Lou et al. 2020; Lee et al. 2021; Long & Ren 2022).

The subsequent recovery phase has sought to capture rebounds in mobility levels. Researchers have exhibited V-shaped trends between two phases (Kim & Kwan 2021; Noi et al. 2022; Kellermann et al. 2022; Yabe et al. 2023). This is reflected in the gradual easing of restrictions when reported cases seemed to be falling sharply. It would be also associated with the phenomenon of “quarantine fatigue”, in which people feel tired of staying at home for several months since strict travel restrictions w (Kim & Kwan 2021; Kwan 2021). Finally, a substantial recovery has been identified in a new steady phase have revealed the restoration of mobility levels and reshaping travel behaviours in a pandemic way, accounting for the final extent of the recovery though less so for public transport (Stanesby et al. 2023) and for vulnerable groups like the elderly (Wang et al. 2022).

In overview, the literature has found that overall mobility levels have evolved throughout the first wave. Also, it has fluctuated widely over a wide range of geographies (Beck & Hensher 2020b), and for population groups by using longitudinal data analysis (Dueñas et al. 2021; Kim & Kwan 2021; Li et al. 2022). Mobility resilience in times of the COVID-19 pandemic can be defined as the capacity to live and develop with change and uncertainty, to minimise the negative impact. However, it could be extended to the ability to bounce back (Wang et al. 2022; Liu et al. 2023; Rockström et al. 2023). A few studies have assessed time-varying mobility resilience by drawing a triangle with mobility reduction and recovery periods, and the quantity of mobility change (Duenas et al. 2021; Wang et al. 2022; Liu et al. 2023), but a focus on the first wave continues to dominate existing literature. This is because of changes and uncertainties in the impact of containment and closure policies to battle COVID-19 during the subsequent waves. The implementation of non-pharmaceutical interventions (NPI) has been neither stable nor consistently effective across space and time (Ge et al. 2022).

Apart from theoretical arguments, trends in mobility may well look differently when the spatial scale at which they are assessed is varied. Therefore, there are theoretical and methodological reasons why paying detailed attention to spatio-temporal trends in mobility is warranted (see the “Discussion” section below). This is why our study accounting for adaptability and resilience has contributed to trajectories of mobility reductions during the first wave that may differ geographically.

To elucidate this issue further, this paper examines how mobility reductions varied over time and space during England's first nationwide lockdown. We used anonymised call-detail records (CDRs) data collected from mobile phones during the entire first wave of the pandemic, spanning from two months before and after the lockdown (i.e., lockdown period with ±2 month). A set of variables have prepared that we expect to be related to place-specific trends in mobility levels. Three sets of variables help to characterise differences in overall mobility changes over space. Sociodemographic profiles composed of income level, occupation, housing type, economic activity, and ethnic composition. Accessibility levels consist of geographic accessibility to health facilities and household car ownership. Local COVID-19 risks in the earliest stages of the pandemic. Not surprisingly, it has become very influential in shaping national policy and public debate whilst also exhibiting distinct geographic differences.

Additionally, the timing and prevalence of government measures can result in differences in COVID-19-related outcomes (Presti et al. 2022) in respect of the degree of fixity among individuals and regional variations (Kim et al. 2017). The relative lateness of England’s national lockdown policies would have contributed to likely increased scale, severity, and duration of the first wave (Arnold et al. 2022). Similarly, the late timing of England’s nationwide second lockdown measures have temporary effects despite strong restrictions and might have resulted in large resurgences of hospitalisations and deaths (Davies et al. 2021).

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