Transportation Research Part A 178 (2023) 103880

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

# The impacts of ridesourcing services on the taxi market: Empirical evidence from England and Wales

Pinar Bilgin [a,*], Giulio Mattioli [b,c], Malcolm Morgan [a], Zia Wadud [d]

[a] Institute for Transport Studies, University of Leeds LS2 9JT, United Kingdom
[b] Urban Development Research Group, Department of Spatial Planning, TU Dortmund University, Dortmund, Germany
[c] School of Earth and Environment, University of Leeds, Leeds LS2 9JT, United Kingdom
[d] Centre for Integrated Energy Research, Institute for Transport Studies and School of Chemical and Process Engineering, University of Leeds, Leeds LS2 9JT, United Kingdom

ARTICLE INFO

*Keywords:*
Ridesourcing
Transportation network companies
Taxi market
Ridesourcing impacts
Difference-in-differences

ABSTRACT

Ridesourcing services have emerged as a major competitor and potential substitute for traditional taxi services. However, research investigating the effects of ridesourcing on the taxi market remains limited, with a focus on specific geographies. This empirical study aims to fill this research gap by examining the impacts of ridesourcing on the taxi market in England and Wales. Using biennial Taxi and Private Hire Vehicle (PHV) Statistics data from the Department for Transport spanning 2005 to 2019, we investigate the impacts of ridesourcing on the number of Hackney Carriages (HCs) and PHVs, as well as the employment patterns in the taxi sector. Our findings indicate a gradual decline in the number of HCs following the introduction of ridesourcing. In contrast, the number of PHVs, which are restricted to pre-bookings, gradually increased. However, we observed no statistically significant change in the number of taxi drivers on average. Notably, our analysis reveals heterogeneous effects across different areas, including rural, urban, and metropolitan districts. Furthermore, we explore the role of regulatory environments in the evolution of ridesourcing and traditional taxi services. Our study highlights that regulation change allowing PHVs to operate across borders may lead to a dramatic increase in the number of PHVs and taxi drivers in specific local authorities. Our research has important implications for policymakers and transportation authorities, particularly in terms of maintaining a competitive taxi market. Furthermore, our findings can inform authorities when planning environmentally sustainable mobility services through the implementation of appropriate regulatory frameworks.

## 1. Introduction

Ridesourcing is a mobility service provided by Transportation Network Companies (TNCs) (e.g., Uber, Ola, Didi and Lyft) that utilise smartphone-based technology to match riders with drivers and enable passengers to follow and manage their trips. Since the introduction of ridesourcing services into the taxi market, they quickly became popular in many countries. However, this rapid rise of ridesourcing has been contentious because of its many impacts on more sustainable modes like public transit and active modes, the environment, traffic, and traditional taxi services.

The competition between traditional taxis and ridesourcing has been discussed since the first introduction of ridesourcing. There is

* Corresponding author.
*E-mail address:* tspbi@leeds.ac.uk (P. Bilgin).

https://doi.org/10.1016/j.tra.2023.103880
Received 26 June 2023; Received in revised form 19 September 2023; Accepted 30 October 2023
Available online 9 November 2023

evidence across the world that ridesourcing has caused traditional taxi ridership to drop significantly (Brown and LaValle, 2021; Fischer-Baum and Bialik, 2015; Nie, 2017; Vega-Gonzalo et al., 2023; Willis and Tranos, 2021; Zhang et al., 2020). This competition between traditional taxi services and ridesourcing arises from the common characteristics of these two services. However, the advantages of ridesourcing over traditional taxis in terms of drivers' and riders' experiences constitute the primary reasons behind the rise of ridesourcing services against traditional taxis. In that sense, ridesourcing services might complement traditional taxis by reaching a wider range of passengers whose demand was unmet before.

Ridesourcing has indeed had implications on travel behaviour and, by extension, the demand for other transport modes, specifically traditional taxis, as they are the major competitors. However, mostly due to the lack of meaningful data, studies remain limited to specific geographies, such as the USA and China. Studies in the related literature regarding the interactions between ridesourcing services and the traditional taxi market generally adopt two approaches. A substantial part of this literature relies on surveys and often asks participants for a substitute alternative for a specific trip in question in the absence of ridesourcing services. At the very early stages of ridesourcing, an intercept survey-based study in San Francisco found that about 40 % of respondents switched from traditional taxis to ridesourcing (Rayle et al., 2016). In Toronto, Canada, one-third of participants stated that if ridesourcing services were not available, they would take a taxi as an alternative to ridesourcing (Loa et al., 2021). In Chengdu, China, if the ridesourcing services are suspended, around 27 % of survey participants would choose taxis, while more than half would choose public transit (Yang et al., 2022). In Bogota, Colombia, more than one-third of ridesourcing users transferred from public transit, while less than 30 % of ridesourcing demand comes from private car users and traditional taxi users (Oviedo et al., 2020). Lastly, 51 % and 36 % of the ridesourcing users in Ghana have shifted from traditional taxis and public transit, respectively (Acheampong et al., 2020). It is worth noting that as opposed to the expectations that ridesourcing has replaced taxi trips, studies that rely on stated preferences revealed that a substantial part of the ridesourcing demand is from prior public transit users, which is concerning from a sustainable transportation and decarbonization point of view.

Another body of the literature focuses mainly on the trip characteristics of the two modes and often utilises GPS tracks or trip records. Based on the spatial and temporal distribution of ridesourcing and taxi trips, researchers compare the service areas and times of the two services to reveal whether ridesourcing competes with or complements traditional taxis. Studies in the USA show that ridesourcing often seems to serve underserved areas located in the city periphery and complements taxi services, while in the downtown area, its operation overlaps with traditional taxis (Bao et al., 2023; Lee et al., 2018; Lin et al., 2017; Pan et al., 2020; Roy et al., 2020). A similar situation applies in China, where ridesourcing competes with traditional taxis under most circumstances, while there is also evidence that ridesourcing complements traditional taxi services where the taxi demand was unmet before ridesourcing (Tang et al., 2021; Wang et al., 2022; Zhang et al., 2020). Regarding temporal distributions, ridesourcing trips are concentrated in morning and evening peaks, and at night when public transit services are not available or scarce. At the same time, there is a more stable demand for traditional taxis during the day (Lin et al., 2017).

It is clear from the literature review that under most circumstances, ridesourcing services intensely compete with and substitute for traditional taxi services because of the similar user and trip characteristics of the two services, which have often resulted in a reduction in the taxi drivers' income. Research shows that after the introduction of Uber into the 50 largest Metropolitan Statistical Areas in the USA, the income of incumbent taxi drivers has reduced by around 10 % (Berger et al., 2018b). In China, the number of daily trips and daily profit per traditional taxi have dropped by 18 % and 19 %, respectively (Jiang and Zhang, 2018). Similarly, in London, drivers of iconic taxis (black cabs) complain about the reduction in demand for black cabs and, by extension, increased working hours and reduced income (Wood et al., 2017).

Although concerns regarding the detrimental effect of ridesourcing on the traditional taxi market have been frequently raised on different platforms, we have a limited understanding of the effects of ridesourcing on demand for traditional taxis and, by extension, the effects on elements of the traditional taxi market. Existing studies in the literature have focused on the demand side and have overlooked the supply side. These studies mostly investigate the substitute alternative to ridesourcing by conducting stated preference surveys or spatiotemporal analysis of taxi and ridesourcing trips without paying attention to the potential changes in the supply side of taxi services. Also, the crossectional nature of the data used in the existing studies may only reveal the association, but not the causality. Lastly, studies regarding the different aspects of ridesourcing services in the Great Britain (GB) context are limited to the impacts of ridesourcing on road accidents (Kirk et al., 2020) and vehicle ownership (Bilgin et al., 2023), and policy implications in London (Mohamed et al., 2019). However, to the best of our knowledge, there are no studies investigating their effects on the taxi market in GB. Existing research in this field overwhelmingly focuses on the USA and China.

In contrast, GB is very different from these countries in terms of the transportation system, built environment characteristics, demographics and culture and, more importantly, regulations as we discuss in Section 2 below. Therefore, this research aims to contribute to the literature by modelling the effects of ridesourcing services on the taxi market in GB using the 2005–2019 Taxi and PHV Statistics released by Department for Transport (DfT) biennially. We used the number of licensed taxi cabs and drivers as metrics that represent the "supply side" of the taxi market. In addition to the average effect, we also consider the potential heterogeneous effects as different characteristics of local authority districts (LADs) groups may potentially affect the outcome, as revealed in Bilgin et al. (2023).

The remainder of the paper is organised as follows. Section 2 presents information about the taxi market and ridesourcing and the taxi regulations in GB. Section 3 explains the modelling approach and design of this research, including the data and variables. Section 4 covers the empirical results of the case study conducted in England and Wales. Section 5 presents a discussion of the results. Finally, Section 6 draws conclusions.

## 2. Overview of the taxi market, ridesourcing and regulations in Great Britain

Taxis are one of the oldest licensed forms of public transport in GB. The first taxi services in GB reach back to the 17th century (Cooper et al., 2010). From the horse-drawn taxis to the first motorized taxi in the late 19th century and then to the modern taxis that we have today, taxis have had an important role in the GB's transportation system historically (Cooper et al., 2010). Although they may not be strictly comparable because of the differences in data sources, Fig. 1 gives insight into the modal share of taxi passenger trips which is relatively high in England as compared to other European countries and the USA.

Today, HCs and PHVs (which include ridesourcing in addition to minicabs, limousines, and chauffeured luxury car services) constitute the taxi market in GB. "Hackney Carriage" is the legal term used in the GB for private ride services that can be hailed on the street or dedicated ranks commonly known as "taxis" (Cooper et al., 2010). PHVs provide private chauffeured rides like HCs but are restricted to pre-booked trips only. The distinction between HCs and PHVs is discussed further in Section 3. For consistency, we use legal terms which are "Hackney Carriage" and "Private Hire Vehicle" here, while we use "taxi" to refer to both HCs and PHVs in the GB context.

Fig. 2 presents the evolution of licensed HCs and PHVs and taxi drivers in England and Wales. It can be observed that the number of HCs remained relatively steady, in contrast to the number of PHVs and taxi drivers, which demonstrated an upward trend both in London and other places in England and Wales. Following the emergence of ridesourcing services, a substantial increase in the number of PHVs is observed both in London, where the ridesourcing services were introduced in 2012 and in other places where ridesourcing services were introduced progressively starting from 2014. The increase in the number of PHVs and taxi drivers might be attributed to the introduction of ridesourcing platforms. Notably, after the regulation change in 2015, the number of taxi drivers increased substantially across England and Wales.

Fig. 3 presents statistics about taxi use in England[1] that may help understand the characteristics of taxi trips and taxi users. In England, taxi trips constitute around 1 % of passenger trips made by all modes on average (Fig. 3a) (Department for Transport, 2022a). Taxis constitute a larger part of urban transport when compared to rural areas. While taxi trips constitute 1 % to 1.65 % of all trips in urban areas, this rate was only 0.5 % in rural areas in 2019 (Fig. 3b) (Department for Transport, 2022b). Taxis are often preferred for leisure trips. In England, around half of the taxi trips are for leisure purposes, while only around 12 % of taxi passengers use them for commuting (Fig. 3c) (Department for Transport, 2022a), and they are mostly used occasionally rather than as the main mode of transport. Around 72 % of people in England rarely use a taxi (less than once a month), and only 9 % are frequent users (at least once a week) (Fig. 3d) (Department for Transport, 2022c). Also, taxi trips tend to be short, as 68 % of taxi trips are under 5 miles (Fig. 3e) (Department for Transport, 2022d). As opposed to the previous literature from other countries that presents a positive association between household income and taxi and ridesourcing use (Aguilera-García et al., 2022; Alemi et al., 2018; Conway et al., 2018; Grahn et al., 2019; Clewlow and Mishra, 2017), in England households that belong to the lowest real income quintile use taxis as the main mode of transport 50 % more when compared to other income groups (Fig. 3f) (Department for Transport, 2022e). Low income is generally negatively related to private car ownership, and access to a private car is among the important factors that affect taxi use, as people without access to private cars often rely on taxis for their travel needs (Lucas et al., 2019). In 2019, in England, 45 % of people who belong to the lowest income quintile have no access to private car (Department for Transport, 2022f). Consistently, in 2019, people without car access made four times as many taxi trips as those with access to a car in England (Department for Transport, 2020a).

Ridesourcing started in the UK after the introduction of Uber in London in 2012 (Uber, 2017), and its popularity has increased rapidly across the UK. Uber has reached 1 billion rides in total less than a decade after its introduction to the UK market (Uber, 2021). There are various factors behind this rapid expansion of ridesourcing services. The regulatory environment is an important factor in the evolution of both traditional taxis and ridesourcing. The taxi market is generally heavily regulated to maintain a certain level of service in most countries. These regulations mainly aim to improve safety, quality, and price fairness as well as to control the number of taxicabs and related externalities by imposing market entry restrictions (Cetin and Deakin, 2019). In such a regulated environment, the introduction of ridesourcing services has caused debates regarding the regulation of these services. Incumbent taxi operators claim that the introduction of ridesourcing services has caused unfair competition. In addition to the inability of traditional taxis to adjust fares dynamically,[2] ridesourcing services are much less regulated than traditional taxis, which are often limited in number with a "medallion system" or "supply cap" in most places (Harding et al., 2016). Therefore, the most prominent endeavour of taxi drivers and operators to slow down the rise of ridesourcing has been to appeal to regulatory authorities to challenge the legality of ridesourcing services (Geradin, 2015) and to restrict ridesourcing operations (Vega-Gonzalo et al., 2023; Wallsten, 2015). One of the most striking examples of this effort has been the case of Uber in London, which has been taken to court several times (Dudley et al., 2017). However, TNCs claim that they should not be imposed the same regulations as taxi companies because they describe themselves as a technology platform that connects riders and drivers rather than a taxi company (Collier et al., 2018; Dudley et al., 2017). In a way, TNCs lower entry barriers to the taxi market and allow ridesourcing vehicles to serve as taxis with fewer regulations and at lower prices.

However, TNCs have confronted legal and regulatory challenges in many countries, including in GB and each country has taken different paths when responding to these disruptive services. For example, in the USA, where the traditional taxi market is heavily

[1] These figures are obtained from the National Travel Survey which is available for England only.

[2] The pricing scheme constitutes one of the important differences, especially between HCs and ridesourcing services. While HCs are required to apply the tariffs determined by the regulatory authorities, ridesourcing fares are market-led. Surge pricing which is one of the pricing strategies that TNCs commonly apply is adjusting prices dynamically based on demand and supply.

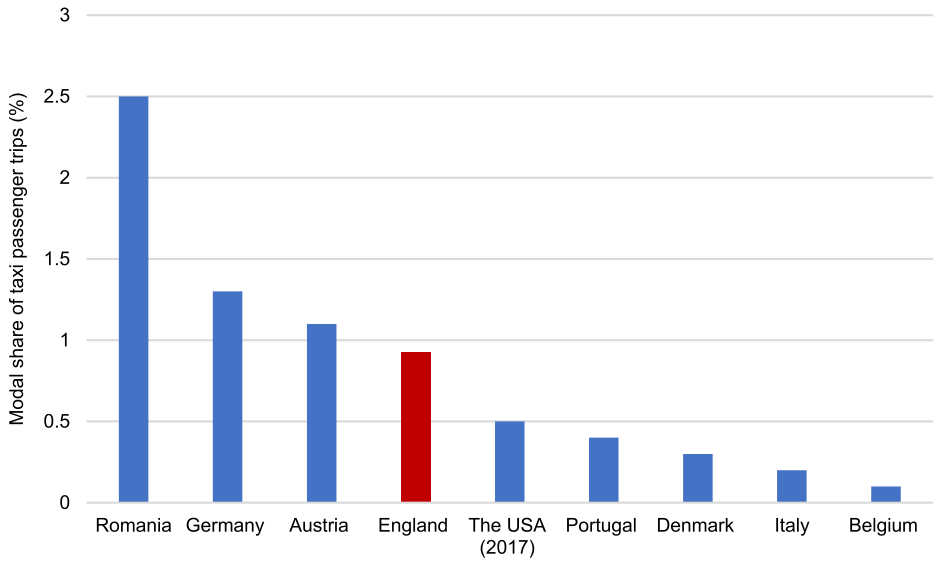



**Fig. 1.** The modal share of taxi passenger trips in England (Department for Transport, 2022a), USA Federal Highway Administration (FHWA), 2017 and selected European countries (Eurostat, 2021).

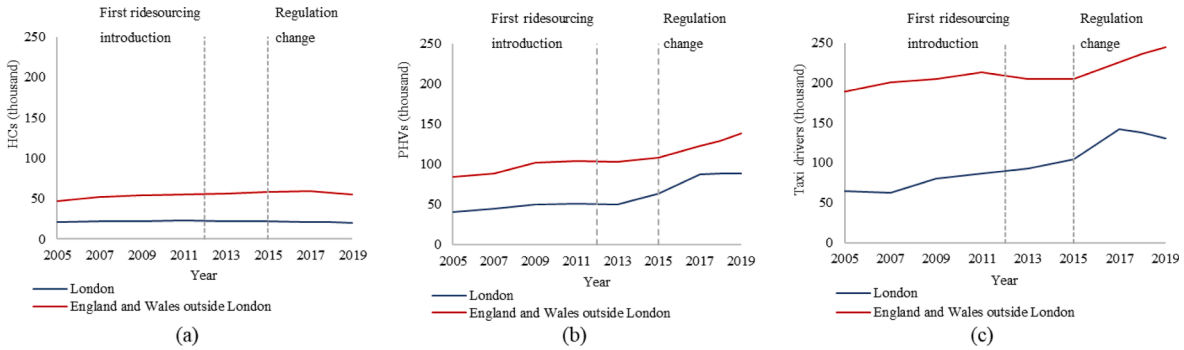
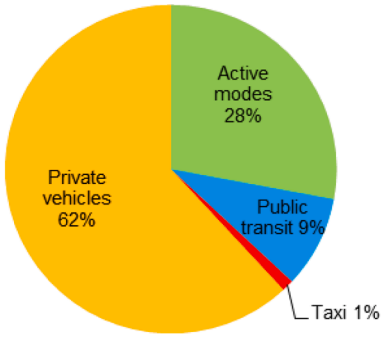



**Fig. 2.** Evolution of the number of licensed (a) HCs, (b) PHVs, and (c) taxi drivers in London and England and Wales outside London (from data table TAXI0101 released by the DfT (Department for Transport, 2019)).

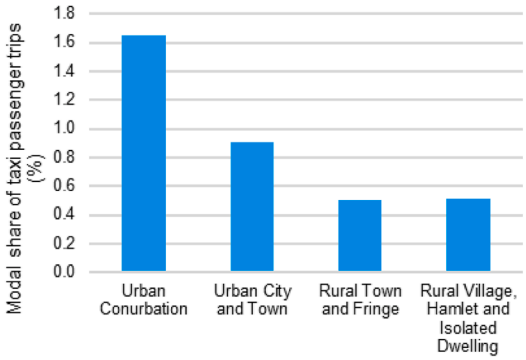
regulated, the regulatory framework has been deregulated and adapted to accommodate ridesourcing services (Thelen, 2018). As a result, the regulatory environment for ridesourcing services in the USA allows anyone to buy a car and become a ridesourcing driver.[3] As opposed to the USA, ridesourcing services were banned in most European countries such as France, Italy, Spain, Germany, Denmark and Hungary because of the reaction from the incumbent taxi operators and licensing, passenger safety and taxation concerns (Curry, 2021; Geradin, 2015; Thelen, 2018). On the other hand, Sweden has placed between the USA case and the European case in terms of its regulatory response to ridesourcing services. Although the traditional taxi market is much less regulated in Sweden than in the USA and aforementioned European countries, existing regulations were adjusted to allow ridesourcing operations without banning them but by making sure they comply with the existing regulations (Thelen, 2018).

GB has taken a similar approach to Sweden when adjusting the regulatory framework for ridesourcing services. In GB, although both types of taxi services are licensed as chauffeured private vehicles to carry passengers, different licensing regulations and restrictions imposed on HCs and PHVs separate them from each other. In GB, Local Authority Councils, except for Greater London Area (GLA), where Transport for London (TfL) is the regulatory authority, are responsible for taxi regulations and operations. In addition to the national minimum standards that aim to protect the public interest, these licensing authorities can set their own standards in their region. Licensing authorities have two important regulatory functions in the taxi market, except for determining the licensing requirements. The first is adjusting the pricing scheme for HCs. The second is limiting the number of HC vehicles, i.e. HC supply cap. Licensing authorities are left to choose whether to apply an HC supply cap. However, they cannot impose limits on the number of PHVs

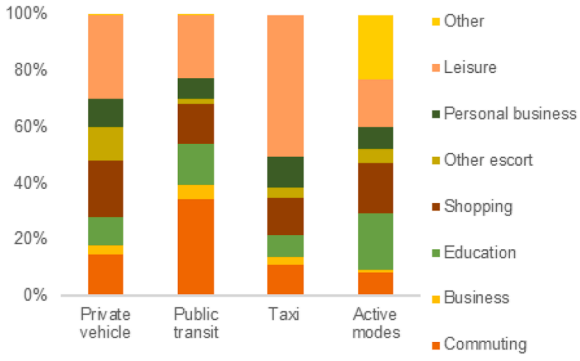
[3] In the US, 36 out of 44 states in which ridesourcing services were available as of 2017, have required TNC permit, while only 6 states have required license for the ridesourcing drivers or operators (Moran et al., 2017).



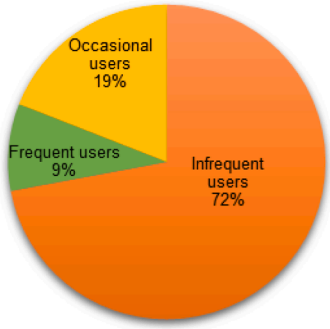

(a)



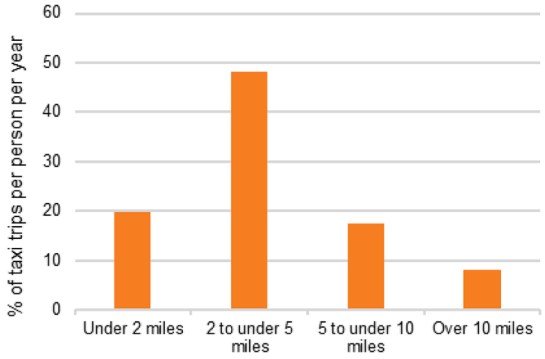

(b)



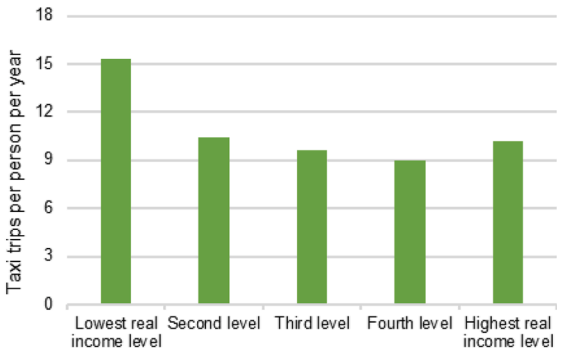

(c)




(d)




(e)




(f)

**Fig. 3.** Statistics about taxi use in England. (a) The modal share of passenger trips (from data table NTS0409 released by the DfT (Department for Transport, 2022a)), (b) the modal share of passenger trips by region types (from data table NTS9903 released by the DfT (Department for Transport, 2022b)), (c) the modal share of passenger trips by trip purpose (from data table NTS0409 released by the DfT (Department for Transport, 2022a)), (d) taxi use frequency (from data table NTS0313 released by the DfT (Department for Transport, 2022c)), (e) the percentage of taxi trips per person per year by trip length (from data table NTS0308 released by the DfT (Department for Transport, 2022d)) and (f) the number of taxi trips per person per year by household income level (from data table NTS0705 released by the DfT (Department for Transport, 2022e)) in England in 2019.

and hence ridesourcing vehicles in GB (Department for Transport, 2020a,b,c). The numerical limit of the HC supply cap is informed by the "Unmet Demand Survey", which is used to ascertain whether there is significant unmet demand for HCs and whether the licensing authority should grant more licenses. These surveys collect data on activity at taxi ranks and from the public.

Regulation regarding the area of operation is another point that has played an important role in the rapid expansion of ridesourcing

services as well as our research design. In the early stages of ridesourcing in GB, ridesourcing vehicles were limited to operating within the licensing area, preventing business expansion across GB, as discussed in the Law Commission's report (Law Commission, 2014). With the change in the taxi and PHV regulations following the Law Commission's report, ridesourcing vehicles have been allowed to operate outside the licensing area, known as cross-border operations, as long as the ridesourcing operator, vehicle, and driver are appropriately licensed by the same licensing authority (Triple License Rule). With Triple License Rule, TNCs have had an opportunity to expand their operation areas and spread around GB.

In GB, most of the driver's license requirements for HC drivers and PHV drivers are very similar. For example, HC drivers and PHV drivers go through similar safety checks. However, in most places, becoming an HC driver requires additional training and qualifications, such as navigational and topological training. London is a good example where HC drivers are required to pass the test known as "The Knowledge", which requires much more effort, time and money to pass compared to PHV drivers' topographical skills test (Wood et al., 2017). However, this proves to be an advantage in some situations as there is evidence that HCs deal with negative traffic conditions better than ridesourcing services thanks to the professional and experienced fleet of drivers (Etminani-Ghasrodashti and Hamidi, 2019).

Then the next question is how the taxi market has reacted to these disruptive mobility services to maintain their competitiveness. In GB, taxi drivers are considered self-employees and are free to sign up for any online booking platform without requiring permission from the licensing authority. After the introduction of large global TNCs such as Uber, Ola, and more recently, Bolt, many taxi companies have adopted app-based hailing either using in-house apps or aggregator platforms (e.g. Kabbee, Karhoo, Minicabit). Addison Lee in London and Amber Cars in Leeds are examples of local PHV companies that successfully implemented app-based hailing systems after global TNCs started operating in GB. In addition to the aforementioned platforms, GETT and Free Now are commonly used HC-exclusive platforms in GB. However, online booking is not always the most convenient and quickest way to get a taxi (Nie, 2017). While HCs can be hailed either by plying for hire, from the taxi ranks or through pre-booking, PHVs are restricted to picking up passengers by pre-booking only. Regulations determining the market forms of taxi services constitute the main differences between HCs and PHVs and one of the major advantages of HCs over ridesourcing services.

Overall, taxis constitute an important part of GB's transportation system. However, the advent of ridesourcing services has clearly changed the way people travel and caused both taxi service providers and regulatory authorities to reconsider their operations. Then, the question is how ridesourcing services have affected the long-standing taxi market in GB where the share of taxi trips is much higher than in many countries and the regulatory environment is much different for TNCs than in the well-studied cases of the USA.

## 3. Methods and data

In this study, we aim to model the effects of the introduction of ridesourcing on the taxi market in GB. However, due to the data availability, we limit our focus to England and Wales (see SI 1 for more information about the study area). When the aim is establishing the effects of an intervention (in our case, the introduction of ridesourcing services) on the outcome of interests, the difference-in-differences (DiD) method is commonly applied. Controlling for the potential impacts of other factors on the outcome of interest, DiD methods establish the causal relationship between intervention and outcomes. We implemented the following fixed-effects model specification:

$$y_{it} = \alpha_i + \alpha_i t + \sum_j \delta_j X_{jit} + \rho Z_{it} W + \beta Z_{it} L + \gamma Z_{it} + \varepsilon_{it} \quad (1)$$

where $y_{it}$ is one of the three dependent variables[4] (number of HCs per 1000 people, number of PHVs, including ridesourcing vehicles, per 1000 people, number of taxi driver's licenses per 1000 people -all in logarithm) for LAD $i$ and time $t$. The number of taxi driver's licenses is calculated as the summation of the number of HC-only driver's licenses, the number of PHV-only driver's licenses and the number of dual driver's licenses. Dual driver's license enables the license holder to work both as an HC driver and PHV driver and causes uncertainty in the determination of the number of active HC drivers and PHV drivers. Therefore, instead of taking the number of HC drivers and PHV drivers separately, we take the total number of taxi drivers (HC and PHV drivers) to avoid any potential bias that may result from this uncertainty. $Z_{it}$ represents the ridesourcing variable. We used three alternative ridesourcing variables. The first alternative is the ridesourcing dummy which indicates whether ridesourcing services are available in LAD $i$ at time $t$ based on the official ridesourcing entry dates (=1 if yes, =0 otherwise) and indicates the average change. The second ridesourcing variable is the 1-year-lagged ridesourcing dummy which relies on the assumption that the effect of ridesourcing entry could only be effective one year after the official entry date and uses the 1-year-lagged version of the first alternative. The last alternative ridesourcing variable is ridesourcing years, which shows how many years ridesourcing services are available in LAD $i$ at time $t$ and indicates the gradual change. $X_{jit}$ is the $jth$ control variable for LAD $i$ and year $t$ with corresponding coefficient $\delta$. The control variables we included in our models are the number of private vehicles per 1000 people[5] (Department for Transport, 2021), vehicle price index (Office for National Statistics, 2021a), gross disposable household income in real terms (GDHI) (Office for National Statistics, 2021b), GDP growth (Office for National Statistics, 2021c), population density (Office for National Statistics, 2020a), job density (Office for National Statistics,

[4] We obtained data from the data table TAXI0104 from Taxi and Private Hire Vehicles Statistics released by the Department for Transport (DfT) biennially (Department for Transport, 2020b).

[5] It is excluded from PHV number models because of multicollinearity.

2020b), number of buses per 1000 people (Department for Transport, 2021), and metro, light rail or tram availability. We also included dummy variables for dual driver's license granting (=1 if respective LAD grants a dual license, =0 otherwise) and HC supply cap (=1 if respective LAD imposes a limit on the number of HC vehicles, =0 otherwise).[6] Also, as the visual inspection of outcome variables reveals, Wolverhampton presents an extreme case. Therefore, to control for its potentially dominant effect, an interaction term- interaction of ridesourcing variable and a dummy variable for Wolverhampton ($W$) with corresponding coefficient $\rho$ - is added in the models. We also added an interaction term of a dummy variable for London ($L$) and ridesourcing variable with corresponding coefficient $\beta$, as London often differentiates from other LADs in many ways such as built environment charateristics and regulatory environment. $\alpha_i$ and $\alpha_i t$ are the LAD-fixed effects and the LAD-specific time trends respectively. Lastly, $\varepsilon_{it}$ is the unobserved error term.

In addition to the average effect of ridesourcing entry, we examined the heterogeneous effect across different groups of LADs by adding interaction terms in the specification presented above. As such, we investigated the effect in different regions by adding interaction terms with dummy variables for each group to reflect the area-group effects (rural LADs, Urban LADs, metropolitan districts) as in Bilgin et al. (2023). In heterogeneous effects models, we followed the specification below:

$$y_{it} = \alpha_i + \alpha_i t + \sum_j \delta_j X_{jit} + \gamma Z_{it} + \rho Z_{it} W + + \beta Z_{it} L + \sum_k \vartheta_k Z_{it} V_{ki} + \varepsilon_{it} \quad (2)$$

where $V_{ki}$ is the dummy variable that represents the *kth* group that each LAD belongs to among three area-groups. $\gamma$ represents the effect in the reference group, while $\vartheta_k$ is the interaction coefficient and shows the difference between the reference group and the *kth* group.

In contrast to standard DiD in which there are single intervention time and two groups- control and treatment-, in our case the intervention times (i.e. ridesourcing entry times) differ across LADs. Hence, we exploited the heterogeneity in ridesourcing entry dates.. We obtained ridesourcing entry date data from three main sources.[7] The first is the existing literature (specifically Kirk et al., 2020) which is mostly based on the entry announcements of TNCs on their websites.[8] The second source is local newspapers that we accessed through the British Newspaper Archive.[9] Lastly, we made Freedom of Information (FoI) requests to licensing authorities. However, due to the Triple License Rule, uncertainties arise when determining the "first" ridesourcing start dates in LADs that do not grant a license to ridesourcing services. As a result of our FoI request, many LAs reported no ridesourcing operation within their boundaries, although we could make a ride request using the smartphone application of Uber, Ola or Bolt. After evaluating the findings from the smartphone application check and three sources mentioned before, we could not find evidence that shows ridesourcing operation in 3 LADs and considered that ridesourcing services are not available in these LADs in our analysis period (2005–2019). Therefore, we relied on 76 LADs[10] with known ridesourcing entry dates in our analyses. Lastly, to interpret the effect as causal, comparison groups should follow similar trends in outcome variables in the pre-ridesourcing period, i.e. parallel trends assumption should be met. We excluded 2 LADs (Gedling and Rossendale) from our analyses because of the discrepancies in outcome variables which may potentially cause the violation of the parallel trends assumption. Visual inspection of the evolution of outcome variables over time suggests that neither individual LADs nor ridesourcing entry cohorts show any clear evidence for violation of the parallel trends assumption after excluding these 2 LADs (see SI 2 for the evolution of outcome variables in pre- and post-ridesourcing periods). Finally, we ended up with 74 LADs. Fig. 4 presents the LADs included in our analysis with corresponding ridesourcing entry dates.

Another methodological issue is that entry decisions of TNCs into LADs may be strategic and may raise endogeneity issues, as TNCs tend to enter large, highly/densely populated areas with potentially higher demand earlier. As shown in Fig. 5, in our case TNCs seem to enter metropolitan districts first, followed by the urban LADs. However, the entry decisions of TNCs that we consider in this study are described as "*more opportunistic than strategic*" (Ward et al., 2019). We further carried out event studies to test whether the estimated effects are the results of the actual ridesourcing entry event or anticipated by other factors. The results of event studies suggest that the introduction of ridesourcing services into LADs (i.e. the variable of interest) is exogenous (see SI 3). Also, in our heterogeneous effects models, we control for the differences between groups that may potentially affect the outcome variables by adding interaction terms into the specification and further reducing the potential bias that may result from this.

Finally, our panel dataset contains observations from 74 LADs over eight periods (from 2005 to 2019 biennially) which may potentially violate some of the fundamental assumptions of OLS. Hence, we checked our models against heteroscedasticity, serial correlation and cross-sectional correlation, and the results suggest violating these fundamental OLS assumptions. Using a nonparametric technique for standard error estimation, the Driscoll-Kraay (DK) estimator produces heteroscedasticity, serial correlation and cross-sectional correlation robust standard errors (Baltagi, 2005; Driscoll and Kraay, 1998). Although cross-sectional dependence is often neglected in this type of panel data analysis, Hoechle (2007) shows that ignoring the violation of these assumptions results in

[6] The dual driving license and HC supply cap variables change over time and between LADs. Out of 74 LADs, 27 LADs have always offered dual driver's licenses, while 13 LADs have never offered dual driver's licenses during the analysis period. In 34 LADs, regulations on dual driver's licenses have changed over time. For the HC supply cap variable, these numbers are 33, 27 and 14 LADs, respectively. This data was obtained from the taxi and PHVs licensing policies data released under the Taxi and PHVs Statistics by the DfT and Freedom of Information requests.

[7] See Bilgin et al. (2023) for complete list of official ridesourcing entry dates into LADs in GB.

[8] https://www.uber.com/en-GB/newsroom/.

[9] The following search terms were used while scanning the newspaper archive: Uber, Ola, Bolt, ridesourcing, ride-hailing, ride-sharing, transportation network companies, private hire vehicles. Also, results were limited to the period of 2010–2019.

[10] Different from Bilgin et al. (2023), we include Greater London Area as a whole in this study rather than London boroughs (City of London and 32 boroughs) because of the data availabiliy.

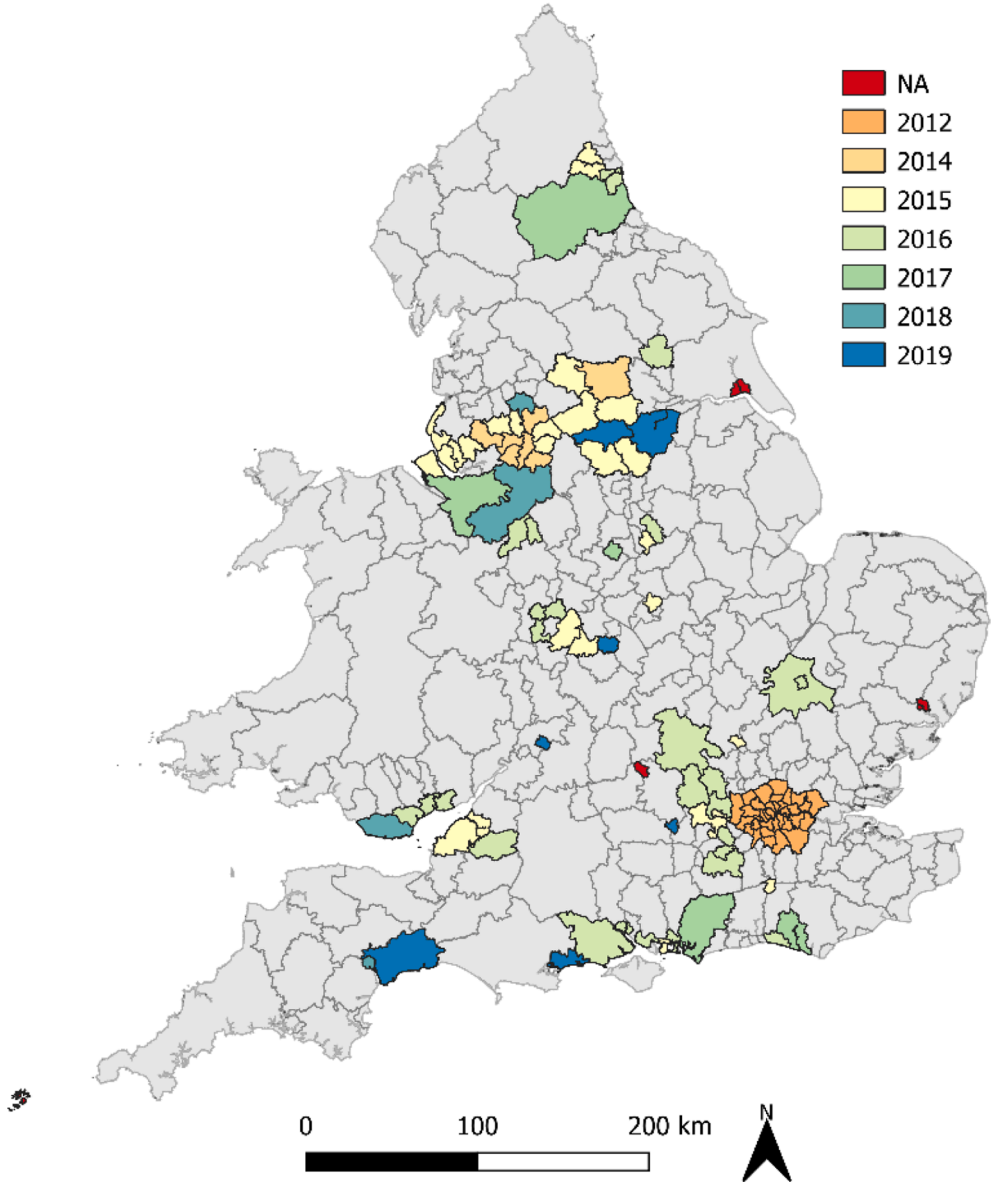



**Fig. 4.** LADs included in this study with ridesourcing launch dates.

biased statistical inference and suggests using the DK estimator when there is cross-sectional dependence, as in our case. Therefore, we use the DK estimator in our analysis and present only the DK estimations here.

We also conducted a series of robustness tests, as suggested by Neumayer and Plumper (Neumayer and Plumper, 2017), to check the stability of our models. These tests include event study, alternative model specifications with alternative ridesourcing variables and the Jackknife test.

## 4. Results

### 4.1. Average effect models

Table 1 summarises the results of the DiD models with DK estimators for three dependent variables. For brevity, we only present the best-fit models in terms of goodness of fit statistics (adjusted $R^2$, AIC, BIC) which are models with ridesourcing years as the variable of interest and suggest gradual change over time. Other models with alternative ridesourcing variables are presented in SI 4 and used as alternative models to test the robustness of the results.

Models 1–3 present the average effect of ridesourcing entry on the number of HCs, number of PHVs, and the number of taxi driver's

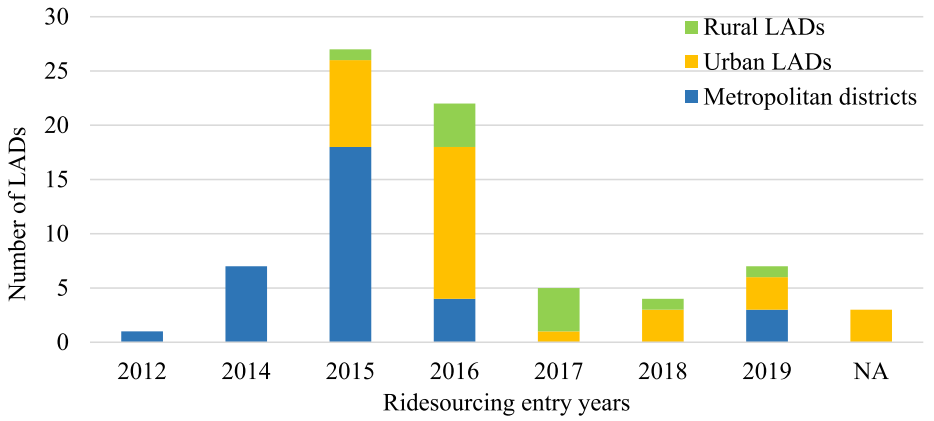



**Fig. 5.** Number of rural LADs, urban LADs and metropolitan districts based on the ridesourcing entry dates.

**Table 1**
Estimation results for baseline models for HC numbers per 1000 people, PHV numbers per 1000 people, the number of taxi driver's licenses per 1000 people.

| Dependent variable | Model 1 HC numbers per 1000 people (ln) | | Model 2 PHV numbers per 1000 people (ln) | | Model 3 Taxi driver license numbers per 1000 people (ln) | |
|---|---|---|---|---|---|---|
| | Estimate | Std. err. | Estimate | Std. err. | Estimate | Std. err. |
| Ridesourcing years | −0.026*** | 0.005 | 0.019** | 0.007 | 0.007 | 0.009 |
| Ridesourcing years × Wolverhampton | −0.060*** | 0.015 | 0.611*** | 0.021 | 0.643*** | 0.037 |
| Ridesourcing years × London | 0.006 | 0.008 | 0.041** | 0.016 | 0.006 | 0.013 |
| Vehicle number per 1000 people (ln) | 0.031 | 0.095 | | | 0.076 | 0.086 |
| Vehicle price index (ln) | −0.240 | 0.624 | −0.274 | 0.403 | 0.609 | 0.426 |
| Gross disposable household income (ln) | −0.012 | 0.008 | −0.023* | 0.011 | −0.024* | 0.012 |
| GDP growth | −0.001 | 0.002 | −0.001 | 0.001 | −0.001 | 0.001 |
| Population density (ln) | 0.478 | 0.531 | 0.812 | 1.094 | −0.753 | 1.026 |
| Job density (ln) | −0.318 | 0.181 | −0.098 | 0.066 | −0.231** | 0.095 |
| Bus number per 1000 people (ln) | 0.020 | 0.014 | −0.082*** | 0.022 | −0.016 | 0.019 |
| HC supply cap | −0.083* | 0.039 | −0.141*** | 0.033 | −0.042 | 0.030 |
| Dual driver's license | 0.057 | 0.035 | 0.011 | 0.026 | 0.004 | 0.022 |
| Rail transport availability | 0.021 | 0.026 | −0.301*** | 0.085 | −0.299*** | 0.068 |
| Constant | −2.773 | 6.222 | −3.377 | 8.541 | 4.052 | 8.278 |
| **Model specification** | | | | | | |
| LAD-fixed effect | Yes | | Yes | | Yes | |
| LAD-specific time trend | Yes | | Yes | | Yes | |
| **Model fit statistics** | | | | | | |
| Adjusted $R^2$ | 0.711 | | 0.680 | | 0.684 | |
| AIC | −1044.5 | | −583.2 | | −856.1 | |
| BIC | −1000.6 | | −543.7 | | −812.3 | |
| Observations | 592 | | 592 | | 592 | |
| **Total effect** (estimated through linear combination) | | | | | | |
| In Wolverhampton | −0.085*** | 0.016 | 0.630*** | 0.019 | 0.650*** | 0.039 |
| In London | −0.020** | 0.008 | 0.060** | 0.021 | 0.012 | 0.015 |
| In other LADs | −0.026*** | 0.005 | 0.019** | 0.007 | 0.007 | 0.009 |

licenses (all in logarithms and are normalized per 1000 people), respectively. These models assume that the effects of ridesourcing entry on outcome variables are homogeneous across the study area. All models include covariates that were mentioned in the previous section, LAD-fixed effect, and LAD-specific time trend.[11]

As we use the continuous ridesourcing years as the ridesourcing variable, the estimated effect captures the differential effect of each additional period (in our case two years) that ridesourcing has been available in the respective LAD on the outcome variables. The results of the average effect models suggest that each additional period of ridesourcing availability has resulted in a 2.6 % decrease and a 1.9 % increase in the number of HCs and PHVs per 1000 people, respectively. We also found a 2 % decrease in HC numbers and a 6.2

[11] We examined the effect of time using various variables such as linear time trend, time-fixed effects, and LAD-specific time trends. Results were consistent across models with overlapping 95% confidence intervals for all variables, indicating similar parameter estimates. Models with LAD-specific time trends showed significantly better goodness of fit statistics, so we present these models only.

% increase in PHV numbers in London. Our average effect models find statistically insignificant changes in the number of taxi driver's licenses per 1000 people. As was visually detected and revealed in SI 2, our results find statistical evidence that Wolverhampton presents an extreme case with an 88 % and a 91.5 % increase in PHV numbers and taxi drivers' numbers every two years with ridesourcing services, respectively. GDHI and job density are negatively related to the number of taxi drivers, which may suggest that ridesourcing may arise as an additional job opportunity. The number of PHVs and taxi drivers is negatively related to rail transport availability. This may suggest that the number of PHVs increases with the poor availability of alternative modes. This may also explain the negative relationships between the number of PHVs and the bus numbers. The lack of alternative modes may cause an increase in demand for taxis.

### *4.2. Heterogeneous effect models*

In this section, the results of heterogeneous effect models are summarised. In the heterogeneous effect models, we investigated area-group effects by including interaction terms of ridesourcing variables and area-group dummies for three area-groups (rural LADs, urban LADs, and metropolitan districts) that differ in built-environment and socio-economic and demographic characteristics. Similar to the previous section, only the best-fit models, which are the models with ridesourcing years as the variable of interest, are presented. Comparisons of coefficients of other models with alternative ridesourcing variables are presented in SI 4.

The results of area-group specific effects models in Table 2 suggest that for every additional period of ridesourcing service availability, the number of HCs per 1000 people decreased by 1.9 % in metropolitan areas, 2.9 % in urban LADs and 4.8 % in rural LADs.. Ridesourcing services have caused an increase in PHV numbers per 1000 people in all area-groups. Rural LADs have experienced a higher increase in the number of PHVs per 1000 people (4.6 %) when compared to metropolitan districts (2 %), while no statistically significant change has been observed in urban LADs. While the number of taxi driver's licenses per 1000 people has not changed overall, it almost doubled in Wolverhampton. The effects of control variables are consistent with the effects in previous models.

## 5. Discussion of results

Our average effect models show that for every additional two years that ridesourcing services were available, the number of HCs decreased by an average of 2.6 % and the number of PHVs increased by an average of 1.9 %. At the same time, it had no statistically significant effect on the number of taxi drivers. Our results demonstrate that the effects of ridesourcing on the taxi market occur gradually, as models with continuous ridesourcing years variables perform better than alternative models. The alternative model specifications presented in SI 4 further support our results.

Gradual change is expected because it takes time for the taxi market to adjust to this new service's emergence (Wadud and Namala, 2022). As was mentioned, HC drivers are allowed to register with ridesourcing platforms as long as they comply with the triple license rule. Ridesourcing services therefore provide additional income opportunities for HC drivers. As a result, the impact may be expected to be lower in the short term. However, in the long term, other factors might become influential. For example, HCs are subject to an age limit and license renewal periods, the frequency and cost of which vary between LADs. It is often easier and cheaper to obtain PHV licenses and is also more attractive to drivers as it offers flexible working hours. In addition, as the adoption rate and popularity of ridesourcing services has increased over time and more people choose ridesourcing services over HCs, it won't be as profitable to operate HCs as it used to be. In these cases, HCs may be taken out of service without replacement if their license has expired or if they are over the age limit. Therefore, these changes are likely to take place gradually after the introduction of ridesourcing services, and this may explain the increasing rate of changes in the number of HCs and PHVs and imply a transition from traditional services to ridesourcing.

A reduction in the number of HCs may be expected because the number of HCs, especially in LADs that impose a supply cap, is generally driven by the demand for HCs, which is quite likely to reduce after the ridesourcing introduction. For example, previous studies suggest that the demand for HCs and hence the income of HC drivers have reduced, while their work hours and empty trips to look for work have increased considerably after the introduction of ridesourcing (Wood et al., 2017). Lower fares and shorter waiting times are among the most pronounced advantages of ridesourcing over HCs that cause the demand to shift from HCs to ridesourcing (Brown and LaValle, 2021). Another often cited reason by taxi users to abandon HCs for ridesourcing is the ease of payment, as ridesourcing services offer seamless online payment to their customers (Brown and LaValle, 2021; Rayle et al., 2016; Wood et al., 2017; Yang et al., 2022) while some of the HCs still only accept cash which arises as one of the major weaknesses of traditional taxis against app-based taxi services (Wood et al., 2017). In GB, as licensing authorities stated, HCs were not mandated to implement a contactless payment system which was changed only after the COVID-19 pandemic[12] in 2020.

An increase in PHV numbers is intuitive, as the introduction of ridesourcing has created new job opportunities with relatively lower capital costs and entry barriers for many people. Whether the increase in PHVs is because of new car purchases or registering existing vehicles as PHVs is not certain. As licensing authorities stated, HCs are allowed to and do sign up for online booking platforms. Therefore, a substantial part of the increase in the number of PHVs may potentially be the registration of existing drivers as ridesourcing service providers with their private vehicles. Supporting this, according to research conducted by Uber in the UK, only a small

[12] We obtained this information from licensing authorities via Freedom of Information request.

**Table 2**
Estimation results for the heterogeneous effect across rural LADs, urban LADs and metropolitan districts.

| Dependent variable | Model 1A HC numbers per 1000 people (ln) | | Model 2A PHV numbers per 1000 people (ln) | | Model 3A Taxi driver license numbers per 1000 people (ln) | |
|---|---|---|---|---|---|---|
| | Estimate | Std. err. | Estimate | Std. err. | Estimate | Std. err. |
| Ridesourcing years | −0.019*** | 0.004 | 0.020* | 0.010 | 0.018 | 0.010 |
| Ridesourcing years × Urban | −0.009 | 0.005 | −0.008 | 0.012 | −0.030*** | 0.005 |
| Ridesourcing years × Rural | −0.029** | 0.012 | 0.025*** | 0.006 | 0.002 | 0.009 |
| Ridesourcing years × Wolverhampton | −0.067*** | 0.015 | 0.611*** | 0.023 | 0.634 | 0.036 |
| Ridesourcing years × London | −0.000 | 0.006 | 0.040*** | 0.011 | −0.006 | 0.014 |
| Vehicle number per 1000 people (ln) | 0.033 | 0.090 | | | 0.036 | 0.071 |
| Vehicle price index (ln) | −0.232 | 0.442 | −0.285 | 0.416 | 0.586 | 0.434 |
| Gross disposable household income (ln) | −0.013 | 0.005 | −0.022* | 0.011 | −0.024* | 0.012 |
| GDP growth | −0.001 | 0.002 | −0.001 | 0.001 | −0.001 | 0.001 |
| Population density (ln) | 0.329 | 0.399 | 0.573 | 0.789 | −1.439 | 0.844 |
| Job density (ln) | −0.343 | 0.180 | −0.099 | 0.060 | −0.272** | 0.095 |
| Bus number per 1000 people (ln) | 0.014 | 0.014 | −0.084*** | 0.019 | −0.028 | 0.020 |
| HC supply cap | −0.080* | 0.035 | −0.140*** | 0.034 | 0.038 | 0.028 |
| Dual driver's license | 0.056 | 0.031 | 0.012 | 0.027 | −0.002 | 0.023 |
| Rail transport availability | 0.029 | 0.031 | −0.287** | 0.093 | −0.259*** | 0.057 |
| Constant | −1.733 | 4.083 | −1.607 | 6.305 | 9.365 | 6.880 |
| **Model specification** | | | | | | |
| LAD-fixed effect | Yes | | Yes | | Yes | |
| LAD-specific time trend | Yes | | Yes | | Yes | |
| **Model fit statistics** | | | | | | |
| Adjusted $R^2$ | 0.713 | | 0.681 | | 0.687 | |
| AIC | −1043.8 | | −580.8 | | −857.9 | |
| BIC | −991.2 | | −532.6 | | −805.3 | |
| Observations | 592 | | 592 | | 592 | |
| **Total effect** (estimated through linear combination) | | | | | | |
| In Wolverhampton | −0.086*** | 0.014 | 0.630*** | 0.019 | 0.650*** | 0.039 |
| In London | −0.020** | 0.007 | 0.059** | 0.021 | 0.011 | 0.015 |
| In rural LADs | −0.049*** | 0.013 | 0.045*** | 0.009 | 0.019 | 0.015 |
| In urban LADs | −0.029*** | 0.004 | 0.012 | 0.008 | −0.012 | 0.008 |
| In metropolitan districts | −0.019*** | 0.004 | 0.020* | 0.010 | 0.018 | 0.010 |

Statistically significant *** at 99%, ** at 95%, * at 90%.

part of Uber drivers do ridesourcing as their sole source of income, but the majority of them have other sources of income or full-time jobs, including taxi driving (Heywood, 2020).

Our heterogeneous effect models revealed that the average effect models overlook the variations across groups. Similar area-based heterogeneous effects were found on vehicle ownership in GB (Bilgin et al., 2023). The largest change in PHV numbers is observed in rural LADs with a 4.6 % increase. There are three potential explanations for this. Firstly, ridesourcing services potentially complement the public transit and traditional taxi services in rural areas where public transit services are scarce, and taxi demand is generally unmet. Especially after the taxi regulation change in 2015, the share of taxi trips per person per year has gradually increased in rural areas (Department for Transport, 2022b) which may be the result of the increasing convenience with the wider availability of ridesourcing services in these areas. Secondly, limited job opportunities in rural areas may be attributed as a possible reason for the significant increase in PHVs in these areas. This can be explained by the emergence of ridesourcing services that have created new job opportunities with lower entry barriers and capital costs, alongside a more flexible work schedule. Lastly, vehicle ownership and use are higher in rural LADs when compared to other areas. Since the number of vehicles per household is already much higher in rural LADs when compared to other areas,[13] people in these regions potentially utilise the excess capacity of their vehicles and work as ridesourcing drivers with their existing cars. This also explains the relatively smaller change in metropolitan districts and no change in urban LADs..

Our models found a statistically insignificant change in the number of taxi drivers following the emergence of ridesourcing services. Given that the number of PHVs has increased and the number of taxi drivers has not changed, there may have been a potential transition of jobs from traditional taxi services to ridesourcing. In our case, it appears that ridesourcing has offered an alternative for existing taxi drivers rather than creating job opportunities for the general public. It is worth emphasising the role of the regulations in this context, as becoming a ridesourcing driver in GB requires possessing a taxi driver's license as well as security checks and additional training and skills. However, Wolverhampton, where both the number of private hire vehicles (PHVs) and taxi drivers nearly doubled, registering a dramatic increase of 87.8 % and 91.5 % respectively, emerges as an extraordinary case. Delving deeper, it was revealed that only around 20 % of registered PHV drivers resided and operated in Wolverhampton in 2017 (Ross, 2017). The easier, faster and

[13] In 2019, more than 50% of households in rural areas has more than two cars, while this rate is 31% in their urban counterparts (Department for Transport, 2020c).

cheaper PHV licensing process in Wolverhampton has led to PHV drivers from other LADs registering in Wolverhampton (Labhart, 2018; Sweeney, 2023). The Wolverhampton case is a very good example of the role of the regulatory environment in balancing the impact of ridesourcing services.

Our models present expected results for London. We found a 6.2 % increase in PHV numbers in London. The high cost of vehicle ownership and restrictions that aim to discourage private vehicle use constitute a high potential demand for private mobility services in London, and hence a profitable market for ridesourcing. Also, higher living costs in London than in other places may potentially result in a further increase in PHV numbers, as people may potentially register ridesourcing platforms to earn extra income. This is also supported by qualitative evidence suggesting that ridesourcing is generally considered as a secondary job that enables earning extra income by most of the ridesourcing drivers (Heywood, 2020). In addition to decreasing demand for HCs, the considerably challenging and expensive process of becoming an HC driver in London (Wood et al., 2017) which potentially cause a shift from HCs to PHVs may explain a slightly larger % decrease in HC numbers in London than in other metropolitan districts. Lastly, the longer period of ridesourcing availability in London may potentially contribute to the relatively larger % changes when compared to other areas as it requires time starting to observe changes.

To sum up, the introduction of ridesourcing has clearly affected the taxi market in England and Wales. However, these effects and the responses from the taxi market are heterogeneous across different geographical area types that we consider in our analysis. Our models highlight the significant effect of regulations in responding to the emergence of ridesourcing services. Also, we find suggestive evidence of a tendency among taxi drivers to shift from fixed-shift traditional taxi services to more flexible ridesourcing driving which is consistent with the findings of previous qualitative research on ridesourcing drivers (Berger et al., 2018b; Hall and Krueger, 2016; Wood et al., 2017).

## 6. Conclusion

Previous research has shown that ridesourcing services have indeed had implications on the taxi market worldwide. However, the effects on the taxi market in different countries vary significantly mainly depending on the regulations that determine the boundaries of traditional taxis' competitive reactions.

Our study reveals the effects of ridesourcing on participants of the taxi market in England and Wales which are particularly interesting because of the high level of taxi use and intermediate levels of regulation between the USA and other European countries. We found a reduction in HC numbers on average. However, decreasing HC numbers is unlikely to help HCs compete with ridesourcing because according to taxi riders, availability and long waiting times are the major issues with traditional taxis (Brown and LaValle, 2021). Also, there is suggestive evidence of a shift towards ridesourcing among existing taxi drivers as PHV numbers significantly increase across the study area while the number of taxi drivers has not changed. Although ridesourcing drivers that shift from traditional taxi companies do not necessarily earn more (Berger et al., 2018a), it seems taxi drivers value other aspects, such as flexible work hours and being self-employed (Hall and Krueger, 2016).

Despite all the competitive disadvantages of traditional taxis, it is unlikely that ridesourcing services will completely replace traditional taxis as they still have an important place in the transportation system because of the traditional street hailing and more stable services with professional drivers (Wang et al., 2022; Zhang et al., 2020). Then the question is *"Will the rise of ridesourcing against HCs continue?"*. Learning from the strengths of ridesourcing services and benefiting from the advantages unique to HCs such as street hailing and a fleet of professional drivers, HCs can maintain or even improve their positions in GB's transportation system. Although regulations imposed on HCs often limit them to react to this intense competition effectively, especially in terms of fares, there may be other ways to respond to these disruptive services, as many taxi users value other aspects such as comfort, safety and convenience more than the trip price (Brown and LaValle, 2021; Wallsten, 2015). For example, there is evidence from the USA that due to the regulations that impede traditional taxis from adjusting prices, traditional taxis improve their qualities such as by improving the cleanness of the vehicles, accepting card payments, improving drivers' attitudes and travel comfort to maintain their competitiveness against ridesourcing services (Wallsten, 2015). Another example is that in Shenzhen, China the online booking system that was available for the use of traditional taxis (Didi Dache) before the introduction of ridesourcing services enables traditional taxis to compete with ridesourcing more effectively and to catch pre-ridesourcing trends faster (Nie, 2017). In GB's context, in addition to the opportunity of synthesising the unique advantages of traditional services and technology, actions towards increasing the quality and efficiency of traditional services can be taken when competing with ridesourcing.

Moreover, this study presents the role of the regulatory environment in the evolution of the taxi market after the emergence of ridesourcing services. As an example of a less regulated ridesourcing market, in the USA, the emergence of ridesourcing services has attracted new drivers by creating job opportunities with low capital cost and entry barriers. Existing regulations for ridesourcing allow individuals to become drivers using their own vehicles without requiring a special driver's license, leading to an increase in the number of people participating in the taxi market and a significant increase in private vehicle numbers (Ward et al., 2021). This has expanded the pool of taxi drivers and resulted in an excess increase in taxi service supply with lower prices and, by extension, a significant decline in taxi medallion values, taxi ridership and taxi drivers' income (Collier et al., 2018). On the other hand, in GB, ridesourcing regulations appear to limit excessive entry into the taxi market and cause a transition from traditional taxi services to ridesourcing among existing drivers rather than attracting many new drivers. As supported by past qualitative studies, ridesourcing has emerged as a secondary job option for many people, particularly for existing taxi drivers (Heywood, 2020). Nevertheless, the impacts of the introduction of ridesourcing services on the demand for traditional taxis and financial outcomes are not certain and need further investigation.

The results of this research may have environmental implications, too. Joint consideration of our results and the results of Bilgin

et al. (2023) presents promising outcomes as the wide availability of ridesourcing services (a statistically significant increase in the number of PHVs per 1000 people after the introduction of ridesourcing that was found in this study) appears to result in a decrease in vehicle ownership (a statistically significant decrease in the number of private vehicles per 1000 people as in Bilgin et al. (2023)) in London and rural areas. This may also imply a decreasing personal private vehicle ownership (i.e. private vehicles that are not in shared use) across GB after the introduction of ridesourcing services. Nevertheless, this does not necessarily mean a reduction in VMT, or emission, as there is evidence that ridesourcing vehicles add extra VMT to the system because of the deadheading and induced travel demand (Henao and Marshall, 2018; Tengilimoglu and Wadud, 2022; Ward et al., 2019). Moreover, average car owners in the UK drive their cars only around 5 % of the time (RAC, 2021), while ridesourcing vehicles are expected to be used more intensely than personal cars which is likely to increase the total VMT and related negative impacts. Therefore, in the long term, authorities should be cautious about the excess increase in vehicle numbers because of the ridesourcing. With proper regulations and incentives, negative outcomes that may result from the increase in PHV numbers can be lowered. In that sense, the electrification of taxis can be encouraged or mandated by authorities as it is potentially easier to impose certain requirements on taxis than on personal vehicles, especially in the context of decarbonization endeavours. As an example, the latest change in PHV licensing requirements in London mandates all PHVs that are licensed for the first time by the TfL to be zero emission capable or meet certain emission standards starting from 2023 (Transport for London, 2020).

Given the effects of ridesourcing are highly location specific, our results for GB may not be directly translated to other countries. Therefore, evidence from other countries, for example, countries where ridesourcing is more strictly regulated than GB, is needed in order to extend the discussion and draw more robust conclusions on the effects of ridesourcing on traditional taxi services, how they react to this intense competition and how the regulatory environment has contributed to or hindered the competitive capabilities of traditional taxi services against ridesourcing to recover their shares in the transportation system.

## CRediT authorship contribution statement

**Pinar Bilgin:** Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft, Visualization. **Giulio Mattioli:** Supervision, Writing – review & editing. **Malcolm Morgan:** Supervision, Writing – review & editing. **Zia Wadud:** Supervision, Writing – review & editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

The authors thank the 2 anonymous reviewers for their constructive suggestions to improve the paper. The first author also thanks the Republic of Türkiye Ministry of National Education for her PhD funding.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tra.2023.103880.

## References

Acheampong, R.A., Siiba, A., Okyere, D.K., Tuffour, J.P., 2020. Mobility-on-demand: An empirical study of internet-based ride-hailing adoption factors, travel characteristics and mode substitution effects. Transp. Res. Part C Emerg. Technol. 115, 102638 https://doi.org/10.1016/j.trc.2020.102638.

Aguilera-García, Á., Gomez, J., Velázquez, G., Vassallo, J.M., 2022. Ridesourcing vs. traditional taxi services: Understanding users' choices and preferences in Spain. Transp. Res. Part A Policy Pract. 155, 161–178. https://doi.org/10.1016/j.tra.2021.11.002.

Alemi, F., Circella, G., Handy, S., Mokhtarian, P., 2018. What influences travelers to use Uber? Exploring the factors affecting the adoption of on-demand ride services in California. Travel Behav. Soc. 13, 88–104. https://doi.org/10.1016/j.tbs.2018.06.002.

Baltagi, B.H., 2005. Econometric analysis of panel data, Third. ed. John Wiley & Sons.

Bao, J., Wang, Z., Yang, Z., Shan, X., 2023. Exploring spatiotemporal patterns and influencing factors of ridesourcing and traditional taxi usage using geographically and temporally weighted regression method. Transp. Plan. Technol. 1–23 https://doi.org/10.1080/03081060.2023.2166510.

Berger, T., Benedikt Frey, C., Levin, G., Rao Danda, S., 2018a. Uber Happy? Work and Well-being in the "Gig Economy". 68th Panel Meet. Econ. Policy Oct. 2018 5, 16–19.

Berger, T., Chen, C., Frey, C.B., 2018b. Drivers of disruption? Estimating the Uber effect. Eur. Econ. Rev. 110, 197–210. https://doi.org/10.1016/j.euroecorev.2018.05.006.

Bilgin, P., Mattioli, G., Morgan, M., Wadud, Z., 2023. The effects of ridesourcing services on vehicle ownership : The case of Great Britain. Transp. Res. Part D 117, 103674. https://doi.org/10.1016/j.trd.2023.103674.

Brown, A., LaValle, W., 2021. Hailing a change: comparing taxi and ridehail service quality in Los Angeles. Transportation (amst). 48, 1007–1031. https://doi.org/10.1007/s11116-020-10086-z.

Clewlow, R.R., Mishra, G.S., 2017. Disruptive transportation: The adoption, utilization, and impacts of ride-hailing in the United States. https://doi.org/10.1139/g01-001.

Cetin, T., Deakin, E., 2019. Regulation of taxis and the rise of ridesharing. Transp. Policy 76, 149–158. https://doi.org/10.1016/j.tranpol.2017.09.002.

Collier, R.B., Dubal, V.B., Carter, C.L., 2018. Disrupting regulation, regulating disruption: The politics of uber in the United States. Perspect. Polit. 16, 919–937. https://doi.org/10.1017/S1537592718001093.
Conway, M., Salon, D., King, D., 2018. Trends in taxi use and the advent of ridehailing, 1995–2017: Evidence from the US National Household Travel Survey. Urban Sci. 2, 79. https://doi.org/10.3390/urbansci2030079.
Cooper, J., Mundy, R., Nelson, J., 2010. Taxi! Ashgate Publishing, Urban economies and the social and transport impacts of the taxicab.
Curry, D., 2021. Ride Hailing Taxi App Market Revenue and Usage Statistics (2021) [WWW Document]. URL https://www.businessofapps.com/data/ride-hailing-app-market/#2.
Department for Transport, 2020a. Taxi and Private Hire Vehicle Statistics: England and Wales 2020 [WWW Document]. Stat, Release https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/944680/taxi-and-private-hire-vehicle-statistics-2020.pdf.
Department for Transport, 2019. Taxi and Private Hire Vehicle Statistics: England and Wales 2019 [WWW Document]. Stat. Release. URL https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/833569/taxi-and-phv-england-2019.pdf.
Department for Transport, 2020b. TAXI0104 Taxis , Private Hire Vehicles (PHVs) and their drivers : England and Wales by licensing area [WWW Document]. URL https://www.gov.uk/government/organisations/department-for-transport/series/taxi-statistics.
Department for Transport, 2020c. Household car ownership by region and Rural-Urban Classification, National Travel Survey.
Department for Transport, 2022a. NTS0409: Average number of trips (trip rates) by purpose and main mode: England, from 2002 [WWW Document]. URL https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons.
Department for Transport, 2022b. NTS9903: Average number of trips (trip rates) by main mode, region and rural-urban classification, England: 2002 onwards [WWW Document]. URL https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons.
Department for Transport, 2022c. NTS0313: Frequency of use of different transport modes, England: 2003 onwards [WWW Document]. URL https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons.
Department for Transport, 2022d. NTS0308: Average number of trips by trip length and main mode: England, 2002 onwards [WWW Document]. URL https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons.
Department for Transport, 2022e. NTS0705: Travel by household income quintile and main mode or stage mode, England: 2002 onwards [WWW Document]. URL https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons.
Department for Transport, 2022f. NTS0703 Household car availability by household income quintile, England: 2002 onwards [WWW Document]. URL https://www.gov.uk/government/statistical-data-sets/nts07-car-ownership-and-access.
Driscoll, J.C., Kraay, A.C., 1998. Consistent covariance matrix estimation with spatially dependent panel data. Rev. Econ. Stat. 80, 549–559. https://doi.org/10.1162/003465398557825.
Dudley, G., Banister, D., Schwanen, T., 2017. The Rise of Uber and Regulating the Disruptive Innovator. Polit. q. 88, 492–499. https://doi.org/10.1111/1467-923X.12373.
Etminani-Ghasrodashti, R., Hamidi, S., 2019. Individuals' demand for ride-hailing services: Investigating the combined effects of attitudinal factors, land use, and travel attributes on demand for app-based taxis in Tehran. Iran. Sustain. 11, 5755. https://doi.org/10.3390/su11205755.
Eurostat, 2021. Passenger mobility statistics [WWW Document]. URL https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Passenger_mobility_statistics#Travel_mode.
Federal Highway Administration (FHWA), 2017. National Household Travel Survey, U.S. Department of Transportation, Washington, DC. [WWW Document]. URL https://nhts.ornl.gov/person-trips.
Fischer-Baum, R., Bialik, C., 2015. Uber Is Taking Millions Of Manhattan Rides Away From Taxis [WWW Document]. URL https://f?veth?rtye?ght.com/features/Uber-?s-tak?ng-m?ll?ons-of-manhattan-r?des-away-from-tax?s/.
Geradin, D., 2015. Should Uber be allowed to Compete in Europe? And If so How? No. 15–29.
Grahn, R., Harper, C.D., Hendrickson, C., Qian, Z., Matthews, H.S., 2019. Socioeconomic and usage characteristics of transportation network company (TNC) riders. Transportation (amst). 47, 3047–3067. https://doi.org/10.1007/s11116-019-09989-3.
Hall, J.V., Krueger, A.B., 2016. Analysis of the Labor Market for Uber'S Driver-Partners in the United States. Nber Work. Pap, Ser, p. 36.
Harding, S., Kandlikar, M., Gulati, S., 2016. Taxi apps, regulation, and the market for taxi journeys. Transp. Res. Part A Policy Pract. 88, 15–25. https://doi.org/10.1016/j.tra.2016.03.009.
Henao, A., Marshall, W.E., 2018. The impact of ride-hailing on vehicle miles traveled. Transportation (amst). 46, 2173–2194. https://doi.org/10.1007/s11116-018-9923-2.
Heywood, J., 2020. The Impact of Uber in the UK: How urban mobility has been transformed.
Hoechle, D., 2007. Robust standard errors for panel regressions with cross-sectional dependence. Stata J. 7, 281–312. https://doi.org/10.1177/1536867x0700700301.
Jiang, W., Zhang, L., 2018. The impact of the transportation network companies on the taxi industry: Evidence from Beijing's GPS Taxi Trajectory Data. IEEE Access 6, 12438–12450. https://doi.org/10.1109/ACCESS.2018.2810140.
Kirk, D.S., Cavalli, N., Brazil, N., 2020. The implications of ridehailing for risky driving and road accident injuries and fatalities. Soc. Sci. Med. 250, 112793 https://doi.org/10.1016/j.socscimed.2020.112793.
Labhart, J., 2018. Why is my taxi from another city? [WWW Document]. accessed 9.13.23 BBC News. https://www.bbc.co.uk/news/uk-england-birmingham-44849364.
Lee, Y., Park, J., Lee, B., 2018. Battle of sharing economy: The contingent effects of ride-sharing on taxi industry, in: Proceedings of the Annual Hawaii International Conference on System Sciences. pp. 656–665. https://doi.org/10.24251/hicss.2018.083.
Law Commission. Taxi and private hire services (Law Com No 347). https://doi.org/10.1177/147377957200100104.
Lin, P., Weng, J., Ma, S., Xu, S., 2017. Data-Driven Operation Characteristics Analysis of Traditional Taxis and Transportation Network Company Cars Pengfei. CICTP. 168–177.
Loa, P., Mashrur, S.M., Nurul Habib, K., 2021. What influences the substitution of ride-sourcing for public transit and taxi services in Toronto? An exploratory structural equation model-based study. Int. J. Sustain. Transp. 1–14. https://doi.org/10.1080/15568318.2021.1978018.
Lucas, K., Stokes, G., Bastiaanssen, J., Burkinshaw, J., 2019. Inequalities in Mobility and Access in the UK Transport System Future of Mobility: Evidence Review Foresight, Government Office for Science 2 Inequalities in Mobility and Access in the UK Transport System.
Mohamed, M.J., Rye, T., Fonzone, A., 2019. Operational and policy implications of ridesourcing services: A case of Uber in London. UK. Case Stud. Transp. Policy 7, 823–836. https://doi.org/10.1016/j.cstp.2019.07.013.
Moran, M., Ettelman, B., Stoeltje, G., Hansen, T., Pant, A., 2017. Policy Implications of Transportation Network Companies: Final Report 1–78.
Neumayer, E., Plumper, T., 2017. Robustness Tests for Quantitative Research. Robustness Tests for Quantitative Research. https://doi.org/10.1017/9781108233590.
Nie, Y., 2017. How can the taxi industry survive the tide of ridesourcing? Evidence from Shenzhen, China. Transp. Res. Part C Emerg. Technol. 79, 242–256. https://doi.org/10.1016/j.trc.2017.03.017.
Office for National Statistics, 2021c. Regional Gross Domestic Product: Local Authorities [WWW Document]. accessed 6.15.21. https://www.ons.gov.uk/economy/grossdomesticproductgdp/datasets/regionalgrossdomesticproductlocalauthorities.
Office for National Statistics, 2020a. Estimates of the population for the UK, England and Wales, Scotland and Northern Ireland - April 2020 Local Authority District Codes [WWW Document]. URL https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalesscotlandandnorthernireland.
Office for National Statistics, 2020b. Jobs density [WWW Document]. URL https://www.nomisweb.co.uk/datasets/jd.
Office for National Statistics, 2021a. Cpi index 07.1 : Purchase of vehicles [WWW Document].
Office for National Statistics, 2021b. Regional gross disposable household income: local authorities by NUTS1 region [WWW Document]. URL https://bit.ly/2Z7j59e (accessed 2.24.22).

Oviedo, D., Granada, I., Perez-Jaramillo, D., 2020. Ridesourcing and travel demand: Potential effects of transportation network companies in Bogotá. Sustain. 12, 1–16. https://doi.org/10.3390/su12051732.
Pan, R., Yang, H., Xie, K., Wen, Y., 2020. Exploring the equity of traditional and ride-hailing taxi services during peak hours. Transp. Res. Rec. 2674, 266–1278. https://doi.org/10.1177/0361198120928338.
Rac, 2021. Cars parked 23 hours a day [WWW Document]. Racfoundation, Org https://www.racfoundation.org/media-centre/cars-parked-23-hours-a-day.
Rayle, L., Dai, D., Chan, N., Cervero, R., Shaheen, S., 2016. Just a better taxi? A survey-based comparison of taxis, transit, and ridesourcing services in San Francisco. Transp. Policy 45, 168–178. https://doi.org/10.1016/j.tranpol.2015.10.004.
Ross, A., 2017. 6000 Wolverhampton taxi licences given out - but most won't ever work in city [WWW Document]. Express. accessed 9.13.23 Star. https://www.expressandstar.com/news/2017/08/29/council-gives-out-more-than-6000-taxi-licences-to-drivers-living-as-far-away-as-southampton/.
Roy, S., Komanduri, A., Proussaloglou, K., 2020. Evolution of Transportation Network Companies and Taxis through 2013–2018 in Chicago. Transp. Res. Rec. 2674, 385–397. https://doi.org/10.1177/0361198120922851.
Sweeney, J., 2023. Wolverhampton council ' inundated ' with private hire licence applications due to lower fees [WWW Document]. Express Star. https://www.expressandstar.com/news/local-hubs/wolverhampton/2023/01/05/city-inundated-with-private-hire-licence-applications/.
Tang, J., Gao, F., Han, C., Cen, X., Li, Z., 2021. Uncovering the spatially heterogeneous effects of shared mobility on public transit and taxi. J. Transp. Geogr. 95, 103134 https://doi.org/10.1016/j.jtrangeo.2021.103134.
Tengilimoglu, O., Wadud, Z., 2022. Evaluating the mileage and time efficiency of ridesourcing services: Austin, Texas case. Transp. Lett. 14, 478–491. https://doi.org/10.1080/19427867.2021.1892936.
Thelen, K., 2018. Regulating uber: The politics of the platform economy in Europe and the United States. Perspect. Polit. 16, 938–953. https://doi.org/10.1017/S1537592718001081.
Transport for London, 2020. Emissions standards for PHVs [WWW Document]. Transp, London https://tfl.gov.uk/info-for/taxis-and-private-hire/emissions-standards-for-phvs.
Transport, 2021 accessed 6.2.21. https://www.gov.uk/government/statistical-data-sets/all-vehicles-veh01.
Uber, 2017. 5 years moving London [WWW Document]. URL https://www.uber.com/en-GB/newsroom/5-years-moving-london/ (accessed 8.1.22)u.
Uber, 2021. Uber to Celebrate One Billion UK Trips [WWW Document]. URL https://www.uber.com/en-GB/newsroom/uber-to-celebrate-one-billion-uk-trips/#:~:text=In just the last three,to or from UK airports. (accessed 8.1.22).
Vega-Gonzalo, M., Aguilera-García, Á., Gomez, J., Vassallo, J.M., 2023. Traditional taxi, e-hailing or ride-hailing? A GSEM Approach to Exploring Service Adoption Patterns. Transportation (amst). https://doi.org/10.1007/s11116-022-10356-y.
Wadud, Z., Namala, J., 2022. The effects of ridehailing services on vehicle ownership in Indian cities. Transp. Res. Interdiscip. Perspect. 15 https://doi.org/10.1016/j.trip.2022.100631.
Wallsten, S., 2015. The Competitive Effects of the Sharing Economy: How is Uber Changing Taxis? Technol. Policy Inst. 1–22.
Wang, D., Miwa, T., Morikawa, T., 2022. Interrelationships between traditional taxi services and online ride-hailing: empirical evidence from Xiamen. China. Sustain. Cities Soc. 83, 103924 https://doi.org/10.1016/j.scs.2022.103924.
Ward, J.W., Michalek, J.J., Samaras, C., Azevedo, I.L., Henao, A., Rames, C., Wenzel, T., 2021. The impact of Uber and Lyft on vehicle ownership, fuel economy, and transit across U.S. cities. iScience 24. https://doi.org/10.1016/j.isci.2020.101933.
Ward, J.W., Michalek, J.J., Azevedo, I.L., Samaras, C., Ferreira, P., 2019. Effects of on-demand ridesourcing on vehicle ownership, fuel consumption, vehicle miles traveled, and emissions per capita in U.S. States. Transp. Res. Part C Emerg. Technol. 108, 289–301. https://doi.org/10.1016/j.trc.2019.07.026.
Willis, G., Tranos, E., 2021. Using 'Big Data' to understand the impacts of Uber on taxis in New York City. Travel Behav. Soc. 22, 94–107. https://doi.org/10.1016/j.tbs.2020.08.003.
Wood, Z., Parry, G., Carruthers, J., Rose, K., 2017. Assessing the Impact of Digital Innovations in the London Transportation Network.
Yang, H., Zhai, G., Yang, L., Xie, K., 2022. How does the suspension of ride-sourcing affect the transportation system and environment? Transp. Res. Part D Transp. Environ. 102, 103131 https://doi.org/10.1016/j.trd.2021.103131.
Zhang, W., Le, T.V., Ukkusuri, S.V., Li, R., 2020. Influencing factors and heterogeneity in ridership of traditional and app-based taxi systems. Transportation (amst). 47, 971–996. https://doi.org/10.1007/s11116-018-9931-2.