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Examining the relationship between different urbanization settings, smartphone use to access the Internet and trip frequencies

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1. Introduction

Several scholars have examined the ways in which new technologies influence people's everyday lives, including where they live, work and shop as well as how they travel (Hong and Thakuriah, 2016; Zhou and Wang, 2014; Zhu, 2013). Most of these studies have utilised census or travel survey data and investigated the relationship between information and communication technologies (ICT)—such as the Internet, cellphone, laptop, computer and fax—and various activities. In addition, the potential endogeneity between ICT use and travel behaviour has been examined (Zhou and Wang, 2014). For example, ICT use may encourage people to make more physical trips. However, it is also possible that people who travel more may use ICT more often to find travel or activity information. Ignoring this potential endogeneity problem could result in a mis-estimated relationship between ICT and travel behaviour.

The smartphone is one type of ICT and its usage has grown rapidly (Pew Research Center, 2015). It has also become fully integrated into our daily lives. It allows people to access the Internet through a cellular network or Wi-Fi even on the move, providing more freedom to users. However, its impacts on travel behaviour have not been examined well, partly due to data limitations. In addition, urbanization settings (e.g., urban and rural areas) could influence both smartphone use and travel behaviour. For instance, the quality of ICT infrastructure is different in urban and rural areas, resulting in digital divide issues (Philip et al., 2015; Schleife, 2010). That is, more urban residents may use a smartphone than rural residents. Moreover, people living in urban areas may drive less than those residing in rural areas because of better accessibility to various activities as well as the public transport system. This is important from a policy perspective because land use policy is often considered a fundamental approach to reduce auto dependency but it could also influence smartphone use which, in turn, can affect travel behaviour.

In sum, urbanization settings, smartphone use and travel behaviour are related in complex ways, but empirical studies on this relationship are scarce. The majority of previous research ignored the interconnections between these factors but examined their relationships independently for decades (i.e., relationship between land use and travel behaviour, or relationship between ICT use and travel behaviour). Therefore, the main aim of this paper is to investigate such complex associations empirically while addressing a well-known methodological issue (i.e., endogeneity) between them. In this paper, we employed the integrated Multi-Media City Data (iMCD) survey (Thakuriah et al., 2016) that includes unique instrumental variables for smartphone use (i.e., computer skills) and an endogenous switching model approach to examine the relationships between urbanization settings, smartphone use to access the Internet and trip frequencies. Specifically, we investigated how different urbanization settings (i.e., large urban areas, other urban areas and town or rural areas) are associated with the smartphone use to access the Internet; and how urbanization settings and smartphone use influence trip frequencies.

2. Literature review

The relationship between ICT and travel behaviour has been studied for several decades (Choo et al., 2007; Clark and Unwin, 1981; Cohen-Blankshtain and Rotem-Mindali, 2016; Roy et al., 2012; Salomon, 1986). Although the results are inconsistent, a substantial number of studies have found significant associations between ICT, activities and travel behaviour. For example, several empirical studies showed the substitution effects of ICT on travel outcomes. Telecommuting is one technology-enabled example where significant reductions were found on motorized trips and related emissions (Balepur et al., 1998; Choo and Mokhtarian, 2005; Helminen and Ristimäki, 2007; Henderson and Mokhtarian, 1996). On the other hand, Mokhtarian (2009) provided several reasons why ICT actively increases travel. ICT may save time and expense which can then be used to generate other activities, and real-time travel information may stimulate additional trips. This argument is supported by the travel time budget theory. Schafer (1998) showed that people spend about 1 h per day on average for travelling regardless of geographies, cultures and different quality of transport infrastructure. This implies that people will make additional trips if they can save travel time by using ICT. Moreover, Lyons and Urry (2005) suggested that new technologies such as mobile devices enable people to do other productive activities (e.g., work) during their travel, potentially reducing the cost of travel time and increasing longer travel.

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Other ICT impacts such as modification and neutrality have also been discussed in several studies (Cohen-Blankshtain and Rotem-Mindali, 2016; Mokhtarian and Tal, 2013; Salomon, 1985).

The smartphone is one type of ICT and different functions embedded in the smartphone such as computing capabilities, apps and Internet connectivity have great potential to influence patterns of behaviour. For instance, people can easily receive real-time traffic information through apps and choose different routes or transport modes to avoid traffic congestion. Tseng et al. (2013) utilised repeated day-to-day revealed-preference observations and found that the exposure to real-time traffic information through a smartphone is significantly associated with travel behavioural changes. Christin et al. (2014) examined the relationship between smartphone adoption and daily activities/travel behaviour among mobile professionals who work > 20% of their time away from their work environments. Although their sample size is small, they argued that mobile professionals do modify daily activities as well as their travel patterns through their use of smartphones. Schwanen and Kwan (2008) argued that the Internet and mobile phone use influence the space-time constraints to some extent (e.g., temporal flexibility), potentially changing peoples' behaviour. Their results also showed the different influences of new technologies on the space-time constraints between genders, which leads to a digital divide issue.

People also use their smartphones for different purposes such as communication, browsing, entertainment and social networking (Falaki et al., 2010; Park and Lee, 2012), which could influence travel behaviour by generating or substituting activities. People may do on-line shopping with their smartphones and save physical trips to shops. On the other hand, online-shopping may increase physical trips because people still want to see the products in stores (Farag et al., 2007; Zhou and Wang, 2014). In addition, there could be bi-directional associations between smartphone use and travel behaviour; people who travel more may use their smartphones more often to find travel or activity information. However, few empirical studies have examined the complex relationship between smartphone use and travel behaviour with a representative sample.

Recent research from the Pew Research Center (2014) showed that smartphone ownership in the U.S. has grown to 58% in 2014 compared to 35% in 2011 and that education level and age are strongly correlated with smartphone use. They also found that smartphone ownership varies according to residential location. Specifically, about 60% of urbanites and suburbanites own smartphones while only 43% of residents in rural areas own smartphones. The trend is very similar in Scotland. About 63% of adults in Scotland own a smartphone (Ofcom, 2015). People in Scotland spent about 20 h per week online, and a smartphone has become one of the most widely used devices for accessing the Internet. Moreover, a higher proportion of adults in urban areas owned a smartphone than those living in rural areas (72% vs. 63%) in 2016 (Ofcom, 2016a). This is not surprising when considering the socio-demographic characteristics of urban residents and the quality of ICT infrastructures. For example, a body of research suggested that young people (e.g., Millennials) are more likely to live in urban areas and use technologies compared to the previous generation (Mcdonald, 2015; Polzin et al., 2014). Moreover, urban areas have a better quality of data networks as well as more Wi-Fi networks in general. Philip et al. (2015) identified that 4G mobile Internet availability is concentrated in urban areas in Scotland. Data from Ofcom (2016b) further showed significant differences in the average broadband download speeds and mobile coverages between urban and rural areas in Scotland. This evidence implies that residential location, specifically urbanization setting, is one of the influential determinants of smartphone use to access the Internet.

This has an important implication for research on the relationship between land use and travel behaviour. This research question has been examined extensively for many years (Ewing and Cervero, 2010; Handy, 2005; Hong et al., 2014; Sun et al., 2015) and most studies have found significant associations between built environment metrics and travel behaviour. For example, Ewing and Cervero (2010) argued that the combined effects of several built-environment factors could be considerable even though each factor has a limited impact on travel behaviour. That is, people living in neighbourhoods with good access to various activities tend to drive less and use other modes of transport more often than those living in isolated areas. Some researchers used different urbanization settings (i.e., urban and rural areas) instead of specific built-environment factors in their analyses. One of their justifications is that urban areas are more compact and better served by other services than rural areas (Hong, 2016). Cao et al. (2010) found that residential location is a very important determinant of driving distance, even after controlling for the self-selection impact. Specifically, one of their results showed that suburban residents tend to drive on average 7.5 miles per day more than urban residents.

The above review suggests several hypotheses concerning the relationship between urbanization settings, smartphone use to access the Internet and travel behaviour. First, people living in urban areas would be more likely to use their smartphones to access the Internet than those living in rural area, partly due to their socio-demographic characteristics and good quality of ICT infrastructure. Second, people living in urban areas are less likely to be dependent on private cars than those living in rural areas because of better accessibilities to various services and public transport systems. Third, people who use their smartphones to access the Internet will have different travel patterns than those who do not. Based on the dominant effects of ICT on travel behaviour from previous empirical research (Mokhtarian, 2009), smartphone use would increase travel. These three hypotheses, if they are correct, imply that different urbanization settings influence travel behaviour directly and indirectly through smartphone use. Understanding their complex relationship is very important to policy-makers and planners because land-use development is a costly, long-term process, and mobile technologies are developing at a much greater speed with immediate consequences. To test the above hypotheses, this study aims to answer two research questions: Are residents in urban areas more likely to use their smartphones to access the Internet than those living in town or rural areas? and how do different urbanization settings (i.e., large urban areas, other urban areas and town & rural areas) and smartphone use influence the frequency of auto, public transport and active travel?

3. Data and empirical model

3.1. Data and variables

Our study area is the Glasgow and Clyde Valley Planning area, United Kingdom. Glasgow is the largest city in Scotland with a population of about 615,000 recorded in 2016. The Glasgow and Clyde Valley Planning area covers eight local authorities including the city of Glasgow and a third of the total population of Scotland. It also produces a third of Scotland's economic outputs (Glasgow and the Clyde Valley Strategic Development Planning Authority, 2017). Recently, the city region has experienced population growth as well as aging growth, which requires careful examinations to provide appropriate social services to residents in the future.

The iMCD household survey was administered in 2015 to collect information about education, sustainability, ICT, civic and cultural activities and transport from residents in the Glasgow and Clyde Valley Planning area. It is a representative home-interview survey[1]; moreover, the main survey as well as one-day travel diary data were collected over 8 months from April to November, 2015. A total of 2095 people from

[1] The survey company confirmed its quality by comparing it with the 2014 Scottish Household Survey data (SHS). SHS samples represent the Scottish population broadly (compared with 2011 Census data by the survey company). A technical report is available from: http://ubdc.ac.uk/media/1322/14-061721-01-technical-report-client-use-only.pdf.

1505 households completed the survey[2]; the household response rate was 51%. The survey data is available for researchers based upon application (http://ubdc.ac.uk/). After removing all missing values, we have data from 1439 individuals for our analyses. The iMCD data also involves an activity diary, GPS and lifelogging (camera device) photographic images from a subset of respondents (Thakuriah et al., 2016).

The survey includes various ICT-related questions.[3] One asks if the interviewee uses the Internet or not. If s/he uses the Internet for personal or work purposes, an interviewer asks which devices (e.g., smartphone, tablet, laptop, smart TV) s/he uses to access the Internet. These two questions were used to create the Smartphone variable. That is, if people do not use the Internet or their smartphones to access the Internet, we defined them as non-smartphone users.

Three trip frequencies (i.e., auto: private car and taxi; public transport: bus, train and underground; and active travel: walking and cycling) were calculated from the one-day travel diary. We identified the main transport mode information for each trip from the diary and calculated how many trips the interviewee made on the date before the Interview. In addition, we employed an urban-rural classification scheme involving 6 categories (i.e., large urban, other urban, accessible small town, remote small town, accessible rural and remote rural areas) developed by the Scottish Government in 2013–2014 to define different urbanization settings. Population calculated based on the settlements dataset from the National Records of Scotland and accessibility measured by driving time to urban areas were taken into account to create this classification (The Scottish Government, 2014). For example, if the population in an area is over 125,000, it is defined as a large urban area. Also, an area with < 3000 residents with an over 30-minute driving time to the nearest city with > 10,000 residents is classified as a remote rural area. The survey company added this classification to each respondent's record based on their home address. For our analyses, we re-categorised it into three: large urban areas (areas of 125,000 or more residents), other urban areas (areas of 10,000 to 124,999 people) and town/rural areas (areas of below 10,000 people). This variable is not as specific as built-environment factors such as the 3Ds (i.e., density, diversity and design) that many land use-travel studies used. However, this simplified urban-rural classification utilised key built-environment factors (i.e., density and accessibility) in the calculation; therefore, we can consider that urban areas are more compact and well-served by other services than town or rural areas. It is worth noting that several land use-travel studies have also employed similar measures (e.g., urban vs. rural) to examine how residential location types influence travel behaviour (Cao et al., 2010; Dieleman et al., 2002; Hong, 2016). Moreover, this simple classification helps to identify the potential digital divide between urban and rural areas because of the fundamental differences in the quality of ICT infrastructure and other factors. Ofcom (2016b) showed that 41% of rural areas in Scotland do not receive mobile data coverage from any operators; this figure is 0% in urban areas. Fig. 1 shows the study area with urbanization settings (Glasgow and Clyde Valley Planning area).

Attitudes towards certain transport modes were also considered. A body of land use-travel studies showed the important role of self-selection in explaining travel behaviour (Bhat and Eluru, 2009; Handy, 2006; Hong and Chen, 2014; Mokhtarian and Cao, 2008). People who have positive attitudes towards active travel or public transport may choose to live in urban areas where they can easily use these transport modes rather than driving. If this is true and attitudes are not considered in the analytical model, the relationship between land use and travel behaviour could be mis-estimated due to the endogeneity problem. Moreover, it is likely that people who dislike driving use their smartphones more often to obtain real-time public transport information. The survey asks how much the person agrees or disagrees with

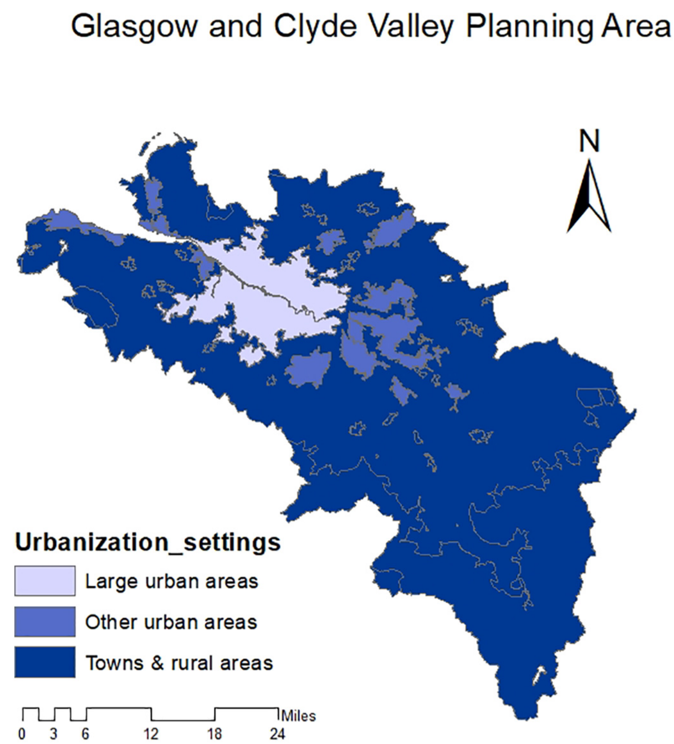

Fig. 1. Study area.

attitudinal statements for different transport modes (e.g., "For me, walking for regular or daily journeys is something I like"). Answers are measured by a 5-Likert scale, anchored by 'strongly disagree' and 'strongly agree'. To relieve the self-selection impact, three transport attitudinal variables (i.e., walking, public transport and driving) were included in our analyses.

The iMCD survey includes a range of questions on the respondents' learning engagement over the preceding 12 months: in formal education (structured/leading to nationally recognised qualifications); non-formal education (structured but not leading to national qualifications); and informal (self-led unstructured or experiential) learning. As noted in Lido et al. (2016), these variables are consistent with the definitions from the International Adult Education Survey (2014) and OECD practices (Werquin, 2010). In our analytical model, among the detailed education and literacy questions, we used two computer-skill-related questions to construct an instrumental variable and address the potential endogeneity between smartphone use to access the Internet and trip frequencies. The survey asks how confident the person is in fixing computer problems such as network issues, as well as in online activities such as making online profiles and uploading videos. Answers are measured by a 4-Likert scale, anchored by 'not at all confident' and 'very confident'. Since these two variables are highly correlated, we combined them to create the Computer Skill variable. That is, the value of the Computer Skill variable ranges from 2 (not at all confident for both skills) to 8 (very confident in both skills). Finally, the various socio-demographic information about each person was considered in the analyses.

Table 1 shows the descriptive statistics for all variables according to urbanization settings. The average age of the individuals in the sample is about 49 years and older for people who live in town or rural areas. About 46% of our observations are male and 53% have either full-time or part-time jobs. On average, 74% hold a valid driving licence while residents in town or rural areas have a higher driving licence ownership compared to those living in urban areas. The average personal net

[2] All adults aged 16 years+ in the household were invited for the interview.

[3] Specific survey questions are presented in Appendix A.

Table 1
Descriptive statistics.

	Total		Large urban areas		Other urban areas		Town/rural areas	
	Mean[a]	SD	Mean[a]	SD	Mean[a]	SD	Mean[a]	SD
Socio-demographics								
Age	48.83	18.08	47.78	17.99	49.61	18.61	51.75	17.13
Gender (male = 1)	46%		45%		47%		47%	
Work (worker = 1)	53%		52%		55%		55%	
Driving licence (own = 1)	74%		70%		76%		87%	
Income (£, person)	15,758	13,847	15,379	13,829	15,347	11,528	18,090	17,263
Household size	2.54	1.32	2.56	1.38	2.45	1.26	2.63	1.15
Attitudes (1: Strongly disagree - 5: Strongly agree)								
Walking	3.85	1.23	3.88	1.24	3.83	1.23	3.79	1.19
Public transport	3.01	1.29	3.09	1.28	2.92	1.34	2.80	1.19
Driving	3.42	1.52	3.31	1.52	3.48	1.58	3.75	1.34
Computer skill (2: Not at all confident - 8: very confident)								
Skill	4.85	2.15	4.91	2.12	4.75	2.18	4.76	2.21
Smartphone use to access the Internet								
Smartphone (use = 1)	62%		65%		59%		56%	
Trip frequencies per day								
Driving	1.74	1.62	1.62	1.70	1.74	1.37	2.24	1.59
Public transport	0.36	0.85	0.44	0.94	0.28	0.72	0.21	0.68
Active travel	0.93	1.48	1.13	1.60	0.65	1.19	0.61	1.29
Sample size	1439		853		380		206	

[a] Percentage for nominal variables.

annual income of our observations is £15,758,[4] and people living in town or rural areas are richer than those living in urban areas on average. The average household size is 2.54, larger for people residing in town or rural areas than those residing in urban areas. People living in urban areas like walking and using public transport more than people living in town or rural areas on average. Conversely, more residents in town or rural areas than urbanites prefer driving. This result suggests the potential role of self-selection in our analyses. That is, people's attitudes towards transport could influence their residential location choice; thus, ignoring attitudinal factors in the analysis could result in an incorrect relationship between urbanization settings and travel behaviour. On average, people living in large urban areas have a higher level of computer skill than residents in town or rural areas. About 62% of those we observed use their smartphones to access the Internet, and the proportion is higher for people living in urban areas than those residing in town or rural areas. This implies the important connection between smartphone use to access the Internet and urbanization settings. Finally, urbanites make more public transport and active trips than people living in town or rural areas on average while generating fewer driving trips.

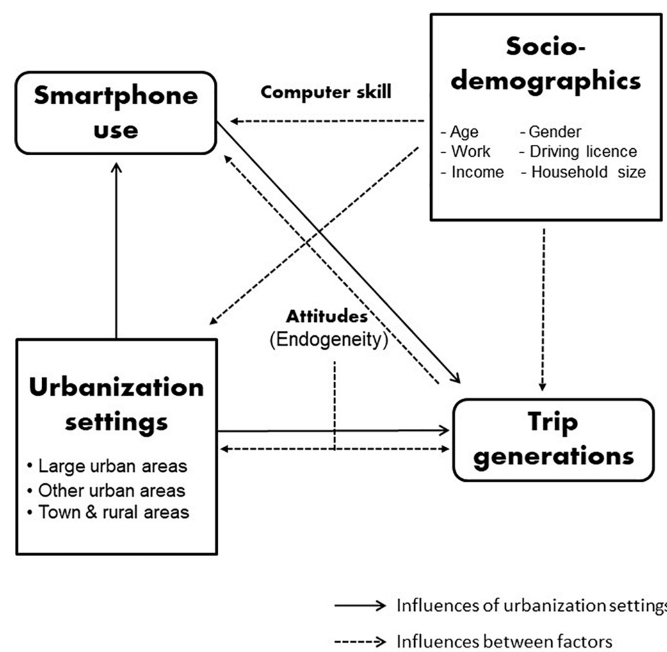

Fig. 2. Framework.

3.2. Empirical model

The main aim of this study is to examine the relationship between urbanization settings, smartphone use to access the Internet and trip generation. Fig. 2 shows the framework of our analysis. Urbanization settings will have a direct influence on trip generation as several land use-travel studies found. However, as discussed in the previous literature, self-selection can play an important role in the land use-travel analysis and can thus lead to an incorrect conclusion. Therefore, attitudes towards transport modes were considered in the model. In addition, urbanization settings could be associated with smartphone use to access the Internet that influences trip generation. If this is true, it implies that smartphone use can act as a mediating factor between urbanization settings and trip generation. However, it should be noted that trip generation can also increase smartphone use to access the Internet (e.g., to find information about transport or activities), causing an endogeneity problem. To solve this problem, we incorporated an instrumental variable (i.e., Computer Skill) and covariance matrix between smartphone use and trip generation within a two-stage approach framework.

A two-stage approach has been widely used in the land use-travel behaviour analysis to identify the direct and indirect impacts of land use on travel behaviour or resolve an endogeneity problem (Hong and Chen, 2014; Khattak and Rodriguez, 2005; Zegras, 2010). A simple two-stage approach works well for continuous outcome variables; however,

[4] This is calculated based on the total net annual income of self-employed, full-time and part-time workers. The average net annual income of full-time workers in our sample is £23,267 and this is reasonable because median hourly pay for workers in Glasgow city is £12.78 (http://www.parliament.scot/ResearchBriefingsAndFactsheets/S4/SB_15-82_Earnings_in_Scotland_2015.pdf).

it could lead to an incorrect conclusion for categorical outcome variables due to the complexity caused by non-linearity characteristics (Miranda and Rabe-Hesketh, 2006). Our two outcomes (i.e., smartphone use and trip frequency) are categorical variables; therefore, we employed a full information maximum likelihood procedure with a covariance matrix to obtain unbiased and efficient estimators (i.e., endogenous switching model approach) (Miranda, 2004).

First, we assumed that smartphone use (S) to access the Internet is a function of socio-demographics (SD), attitudes (ATT), urbanization settings (US) and computer skill (CK), based on which a probit model was utilised:

$$S_i = \begin{cases} 1 & \text{if } \alpha + \beta_{SD}^{\top}x_{SDi} + \beta_{ATT}^{\top}x_{ATTi} + \beta_{US}^{\top}x_{USi} + \beta_{CK}x_{CKi} + \upsilon_i > 0 \\ 0 & \text{Otherwise} \end{cases}, \quad \text{for i} = 1, \ldots, \text{n} \tag{1}$$

where, x_{SD}, x_{ATT}, x_{US}, x_{CK} and n represent diverse socio-demographics, attitudes towards transport modes, urbanization settings, computer skill and sample size, respectively. Here, υ_i represents random error terms that follow a normal distribution with mean 0 and variance 1. Second, a quasi-Poisson model was used to analyse trip generation behaviour based on the information pertaining to socio-demographics, attitudes, urbanization settings and smartphone use to access the Internet as well as overdispersion of the data.

$$\Pr(y_i;\text{u}_\text{i}) = \frac{u_i^{y_i}\exp(-u_i)}{y_i!}, \text{ for i} = 1, \ldots, \text{n}$$
$$\text{u}_\text{i} = \exp(\gamma + \gamma_{\text{SD}}^{\text{T}}\text{x}_{\text{SDi}} + \gamma_{ATT}^{\text{T}}\text{x}_{\text{ATTi}} + \gamma_{\text{US}}^{\text{T}}\text{x}_{\text{USi}} + \gamma_{\text{smartphone}}X_{Si} + \varepsilon_i) \tag{2}$$
$$\varepsilon_i \sim N(0, \sigma^2)$$

where, y, u and ε represent trip frequency, mean and random error terms caused by omitted and unobserved variables, respectively. One of the key model assumptions for a Poisson model is that the variance equals the mean. However, this assumption is often violated, requiring extra care. Since ε_i follows a normal distribution with mean 0 and standard deviation (σ) as seen in Eq. (2), σ represents the amount of overdispersion (e.g., if $\sigma \neq 0$ and positive, data is over-dispersed) and our model considers the impacts due to such overdispersion. Then the covariance matrix can be written as:

$$\sum = \begin{pmatrix} \sigma^2 & \sigma\rho \\ \sigma\rho & 1 \end{pmatrix} \tag{3}$$

If endogeneity between the above two models exists, it indicates $\rho \neq 0$. If $\rho = 0$, smartphone use to access the Internet (X_S) in Eq. (2) can be considered as an exogenous variable. A likelihood-ratio test is used for testing it by comparing log-likelihoods from models with or without ρ (Miranda, 2004). For the analysis, three continuous socio-demographic variables (i.e., Age, Income and Household size) were standardized by using their means and standard deviations, and Stata was used with the espoisson command.

4. Results

Table 2 shows the results of smartphone use to access the Internet and trip generation for different transport modes. Most socio-demographic variables show very significant associations with smartphone use. Older people are less likely to use their smartphones to access the Internet while holding other factors constant. Age is one of the key determinants of Internet use as well as smartphones (Pew Research Center, 2015), and younger people tend to use mobile technologies more than older people. Women are more likely to use their smartphones than men, and workers tend to use their smartphones more to access the Internet than non-workers. This is consistent with smartphone ownership data from Statista (2016), showing that 62.5% females own a smartphone while 59.5% of male have a smartphone in the U.K. People who hold a valid driving licence are more likely to use their smartphones than those without a driving licence. This may indicate that people who are mobile use their smartphones more to access the Internet than others who are not. Total personal income has a positive correlation with smartphone use to access the Internet while holding other factors constant. That is, higher income people are more likely to use their smartphones than low income people. Income is another important determinant of smartphone use (Pew Research Center, 2014). People from a large household are more likely to use their smartphones to access the Internet than those from a small household, while holding other variables constant. This may be due to the availability of devices to access the Internet. Only a limited number of household members can use desktops or laptops to access the Internet at the same time. One of the three attitudinal factors shows a significant association with smartphone use to access the Internet at the 0.1 level of significance. Specifically, as people like walking more, they are less likely to use their smartphones to access the Internet.

One of the two urbanization variables shows a positive and significant association with smartphone use at the 0.1 level of significance. That is, people residing in large urban areas are more likely to use their smartphones to access the Internet than those living in town or rural areas. This result confirms our first hypothesis. Large urban areas have better infrastructure (e.g., 4G networks and Wi-Fi services) which improves the mobile device experience, leading to greater use of smartphones to access the Internet. Extra analyses show that its correlation becomes significant at the 0.05 level of significance if attitudinal factors are ignored, because attitudes are correlated with residential location choice as well as smartphone use. Finally, the result shows that technically-oriented people, as measured by the composite computer skills variable, are more likely to use their smartphones to access the Internet than those who have limited knowledge of computers or web skills.

Most socio-demographic variables show significant correlations with different types of trip frequency, and the results are consistent with previous studies in general. As people become older, they tend to generate more auto trips. In addition, men travel less by auto and public transport than women. These results are consistent with the Hong and Thakuriah (2016) study that used the 2005–6 Scottish Household Survey. Workers tend to make more auto trips but fewer active travel trips than non-workers. This could be related to commuting behaviour and time constraints. Having a valid driving licence is positively correlated with an auto-trip generation but negatively related with the frequencies of public transport and active travel trips. As household size increases, people tend to generate more auto trips but fewer public transport trips. This can be due to the additional escort trips for their children to different activity places as well as travel cost. For example, private cars and taxis can be cheaper than public transport if several people travel together.

Attitudes towards transport modes show very significant associations with all types of trip generation. Specifically, people who like walking tend to generate more active travel trips but fewer auto trips. In addition, people who like driving generate more auto trips but fewer public transport and active travel trips. These results are consistent with previous studies (Handy, 2006; Hong et al., 2014), implying the potential self-selection influence on travel behaviour.

Two urbanization settings show very significant and negative associations with an auto trip generation. This confirms our second hypothesis. That is, people living in large or other urban areas tend to generate fewer auto trips compared to those residing in town or rural areas. As mentioned, large urban areas are more densely populated and include a wide range of services compared to town or rural areas. Therefore, this result implies that built environment factors are very important determinants of trip generation behaviour. The results also show that people living in large urban areas are more likely to make public transport and active travel trips than residents in town or rural areas.

Smartphone has a statistically significant influence on the number

Table 2
Results of smartphone use to access the Internet and trip generation for different transport modes with a covariance matrix.

	Driving				Public transport				Active travel			
	Smartphone use		Trip generation		Smartphone use		Trip generation		Smartphone use		Trip generation	
	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Intercept	−1.10	0.00	−0.17	0.23	−1.09	0.00	−2.74	0.00	−1.08	0.00	−1.58	0.00
Socio-demographics												
Age	−0.64	0.00	0.26	0.00	−0.64	0.00	−0.43	0.00	−0.64	0.00	−0.20	0.04
Gender (Male = 1)	−0.23	0.01	−0.20	0.00	−0.23	0.01	−0.36	0.01	−0.23	0.01	0.10	0.27
Work (Worker = 1)	0.24	0.02	0.16	0.01	0.24	0.02	0.32	0.06	0.24	0.02	−0.60	0.00
Driving licence (Own = 1)	0.49	0.00	0.74	0.00	0.49	0.00	−0.60	0.00	0.49	0.00	−0.28	0.04
Total income	0.17	0.00	0.00	0.98	0.17	0.00	0.03	0.72	0.17	0.00	0.01	0.90
Household size	0.11	0.03	0.11	0.00	0.11	0.03	−0.36	0.00	0.11	0.03	−0.02	0.66
Attitudes (1: Strongly disagree – 5: Strongly agree)												
Walking	−0.07	0.08	−0.04	0.02	−0.07	0.07	−0.10	0.08	−0.07	0.07	0.32	0.00
Transit	0.02	0.51	−0.09	0.00	0.03	0.49	0.51	0.00	0.03	0.49	0.07	0.07
Driving	−0.06	0.11	0.11	0.00	−0.06	0.10	−0.16	0.01	−0.06	0.10	−0.16	0.00
Residential locations (Reference: Town&rural areas)												
Large urban areas	0.24	0.06	−0.16	0.01	0.25	0.06	0.51	0.04	0.25	0.06	0.46	0.00
Other urban areas	0.10	0.48	−0.14	0.04	0.10	0.47	0.04	0.88	0.10	0.47	−0.08	0.65
Computer skill												
Skill	0.29	0.00			0.29	0.00			0.29	0.00		
Smartphone use (use = 1)												
Smartphone			0.32	0.04			−0.10	0.83			0.13	0.66
σ			0.27	0.00			1.39	0.00			1.06	0.00
ρ			−0.33	0.32			0.01	0.98			−0.02	0.91
Log likelihood			−2827.83				−1528.48				−2334.29	
Likelihood-ratio test (ρ = 0)				0.71				1.00				0.89

of auto trips at the 0.05 level of significance. Specifically, people who use their smartphones to access the Internet tend to make more auto trips, all other variables being constant. This result confirms the third hypothesis. Diverse smartphone apps could enable people to make more efficient car journeys by accessing traffic information and avoiding traffic congestion. In addition, smartphone use could encourage travel because it is easier for individuals to get activity information and make changes to their travel plans. Combined with the previous result (i.e., residents in large urban areas are more likely to use their smartphones to access the Internet than those living in town or rural areas), this implies that there could be a significant mediated impact of different urbanization settings on auto trip generation through smartphone use.

Finally, the results show that σ (Dispersion) is positive and not equal to zero (i.e., our data is over-dispersed) and ρ is not statistically significant. Also, all likelihood-ratio tests[5] fail to reject the null hypothesis (i.e., ρ = 0: no endogeneity exists between smartphone use to access the Internet and trip generation), implying that smartphone use can be treated as an exogenous variable in our trip generation models. The results assuming that ρ = 0 are shown in Table 3 and consistent with previous results. Smartphone has a positive and significant influence on auto trip generation and its magnitude becomes smaller.

5. Conclusion

New technologies, including the Internet and mobile devices, have enriched people's daily life, providing great freedom to users. In particular, the easy access to the Internet and real-time travel information has great potential to help people modify their activities and travel behaviour. However, few empirical studies have investigated the relationship between smartphone use to access the Internet and travel behaviour as well as the connection between urbanization settings, smartphone use to access the Internet and travel behaviour. In this study, we utilised an endogenous switching model with attitudinal factors to examine their complex relationships while relieving the endogeneity impacts between them.

Our results show that although the association is marginally significant, people living in large urban areas are more likely to use their smartphones to access the Internet than those residing in town or rural areas. The number of Internet users in Britain has increased rapidly; however, the quality of ICT infrastructure in rural areas is not as good as in urban areas, resulting in a slower connection speed as well as potential urban-rural digital divide among users (Philip et al., 2015).

Second, we find that urbanization setting is an important determinant of different types of trip generation. People residing in large or other urban areas tend to make fewer car journeys compared to those living in town or rural areas while controlling for other important factors. In addition, residents in large urban areas are more likely to generate public transport and active travel trips, supporting the effectiveness of urban growth management strategies. This finding implies that encouraging infilled developments in the Glasgow and Clyde Valley Planning area could lead to a more environmentally friendly society.

Third, our results identify the significant complementarity influence of smartphone use to access the Internet concerning auto trip generation. Advanced mobile technologies allow people to access diverse information easily, enabling them to participate in more activities (i.e., more trips). Moreover, people can make efficient driving trips by searching real-time traffic information through their smartphones before or during their trips. Based on the answers for other ICT-related questions in the iMCD survey, we found that quite a number of workers in our sample with smartphones have used navigation apps, websites and system to get travel information (e.g., direction, trip times, etc.) when making car trips at least sometimes in the month preceding that in which the interview was conducted. This implies that new mobile technologies could improve the quality of life but may also aggravate environmental problems, requiring more careful examinations in the future.

Finally, we identify the potential indirect influence of different

[5] Likelihood ratio tests were conducted based on the log likelihood values from Tables 2 and 3.

Table 3
Results of smartphone use to access the Internet and trip generation for different transport modes without a covariance matrix (ρ = 0).

	Driving				Public transport				Active travel			
	Smartphone use		Trip generation		Smartphone use		Trip generation		Smartphone use		Trip generation	
	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Intercept	−1.09	0.00	−0.10	0.41	−1.09	0.00	−2.74	0.00	−1.09	0.00	−1.56	0.00
Socio-demographics												
Age	−0.64	0.00	0.22	0.00	−0.64	0.00	−0.43	0.00	−0.64	0.00	−0.21	0.00
Gender (Male = 1)	−0.23	0.01	−0.20	0.00	−0.23	0.01	−0.36	0.01	−0.23	0.01	0.10	0.28
Work (Worker = 1)	0.24	0.02	0.18	0.00	0.24	0.02	0.32	0.05	0.24	0.02	−0.60	0.00
Driving licence (Own = 1)	0.49	0.00	0.76	0.00	0.49	0.00	−0.60	0.00	0.49	0.00	−0.28	0.04
Total income	0.17	0.00	0.01	0.74	0.17	0.00	0.03	0.71	0.17	0.00	0.01	0.87
Household size	0.11	0.03	0.11	0.00	0.11	0.03	−0.36	0.00	0.11	0.03	−0.02	0.67
Attitudes (1: Strongly disagree – 5: Strongly agree)												
Walking	−0.07	0.07	−0.05	0.01	−0.07	0.07	−0.10	0.08	−0.07	0.07	0.32	0.00
Transit	0.03	0.49	−0.09	0.00	0.03	0.49	0.52	0.00	0.03	0.49	0.07	0.07
Driving	−0.06	0.10	0.11	0.00	−0.06	0.10	−0.16	0.00	−0.06	0.10	−0.16	0.00
Residential locations (Reference: Town&rural areas)												
Large urban areas	0.25	0.06	−0.15	0.01	0.25	0.06	0.50	0.03	0.25	0.06	0.47	0.00
Other urban areas	0.10	0.47	−0.14	0.04	0.10	0.47	0.04	0.88	0.10	0.47	−0.07	0.65
Computer skill												
Skill	0.29	0.00			0.29	0.00			0.29	0.00		
Smartphone use (use = 1)												
Smartphone			0.18	0.00			−0.09	0.66			0.10	0.43
σ			0.27	0.00			1.37	0.00			1.06	0.00
Log likelihood			−2828.26				−1528.48				−2334.30	

urbanization levels on trip generation through smartphone use to access the Internet. People living in large urban areas are more likely to use their smartphones to access the Internet than those living in town or rural areas. Moreover, using smartphone to access the Internet is positively associated with the frequency of auto trips. This implies that ignoring the mediated impacts of urbanization settings (i.e., residential location) could result in the over-estimated influences of urbanization settings on travel behaviour. Therefore, planners and policy makers should understand their complex relationships to make better plans and policies.

There are limitations of our study. First, the survey allows us to utilise only a simple measure of smartphone use to access the Internet. Using the intensity of smartphone use (e.g., frequency) for different activities would provide more useful information for planners and policy makers. Therefore, future travel surveys should include specific smartphone use questions in order to disentangle the complex relationship between smartphone use and travel behaviour. Second, using specific built-environment metrics to define residential locations could improve our analysis. Third, controlling for self-selection impacts based on attitudinal factors is limited. Using panel surveys with information about attitudinal changes would be helpful in future studies to address the self-selection impacts more thoroughly. Lastly, travel information from a one-day travel diary may differ from actual travel patterns due to interviewees' memory decay or ignorance of short trips. Therefore, utilising objective measures of travel outcomes could provide more accurate results.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jtrangeo.2018.04.006.

References

Adult Education Survey, 2014. Adult Education Survey 2011 European Quality Report, European Commission Report. Retrieved from. Eurostat, Luxembourg.

Balepur, P.N., Varma, K.V., Mokhtarian, P., 1998. Transportation impacts of conter-based telecommuting: interim findings from the neighborhood telecenters project. Transportation 25, 287–306.

Bhat, C.R., Eluru, N., 2009. A copula-based approach to accommodate residential self-selection effects in travel behavior modeling. Transp. Res. B 43, 749–765.

Cao, X., Xu, Z., Fan, Y., 2010. Exploring the connections among residential location, self-selection, and driving: propensity score matching with multiple treatments. Transp. Res. A Policy Pract. 44, 797–805.

Choo, S., Mokhtarian, P., 2005. Does Telecommuting Reduce Vehicle-Miles Traveled? An Aggregate Time Series Analysis for the U.S. Transportation. 32. pp. 37–64.

Choo, S., Lee, T., Mokhtarian, P., 2007. Do transportation and communications tend to be substitutes, complements or neither? Tranp. Res. Rec. 2010, 121–132.

Christin, G.N., Tamin, O.Z., Santoso, I., Miharja, M., 2014. Adjustment of daily activities: the influence of smartphone adoption on the travel pattern of mobile professionals in the Greater Jakarta Area. J. Eng. Technol. Sci. 46, 394–409.

Clark, D., Unwin, K.I., 1981. Telecommunications and travel: potential impact in rural areas. Reg. Stud. 15, 47–56.

Cohen-Blankshtain, G., Rotem-Mindali, O., 2016. Key research themes on ICT and sustainable urban mobility. Int. J. Sustain. Transp. 10, 9–17.

Dieleman, F.M., Dijst, M., Burghouwt, G., 2002. Urban form and travel behaviour: micro-level household attributes and residential context. Urban Stud. 39, 507–527.

Ewing, R., Cervero, R., 2010. Travel and the built environment. J. Am. Plan. Assoc. 76 (3), 265–294.

Falaki, H., Mahajan, R., Kandula, S., Lymberopoulos, D., Govindan, R., Estrin, D., 2010. Diversity in Smartphone Usage. (Paper presented at the ACM SIGCOMM IMC).

Farag, S., Schwanen, T., Dijst, M., Faber, J., 2007. Shopping online and/or in-store? A structural equation model of the relationships between e-shopping and in-store shopping. Transp. Res. A Policy Pract. 41 (2), 125–141. http://dx.doi.org/10.1016/j.tra.2006.02.003.

Glasgow and the Clyde Valley Strategic Development Planning Authority, 2017. Strategic Development Plan: Delivering Growth in the Glasgow City Region.

Handy, S., 2005. Critical assessment of the literature on the relationships among transportation, land use, and physical activity. In: TRB Special Report 282: Does the Built Environment Influence Physical Activity? Examining the Evidence.

Handy, S., 2006. Self-selection in the relationship between the built environment and walking. J. Am. Plan. Assoc. 72, 55–74.

Helminen, V., Ristimäki, M., 2007. Relationships between commuting distance, frequency and telework in Finland. J. Transp. Geogr. 15 (5), 331–342. http://dx.doi.org/10.1016/j.jtrangeo.2006.12.004.

Henderson, D.K., Mokhtarian, P., 1996. Impact of center-based telecommuting on travel and emissions: analysis of the Puget Sound demonstration project. Transp. Res. D 1 (1), 29–45.

Hong, J., 2016. How does the seasonality influence utilitarian walking behaviour in different urbanization settings in Scotland? Soc. Sci. Med. 162, 143–150.

Hong, J., Chen, C., 2014. The role of the built environment on perceived safety from crime and walking: examining direct and indirect impacts. Transportation 41, 1171–1185. http://dx.doi.org/10.1007/s11116-014-9535-4.

Hong, J., Thakuriah, P., 2016. Relationship between motorized travel and time spent online for

nonwork purposes: an examination of location impact. Int. J. Sustain. Transp. 10 (7), 617–626. http://dx.doi.org/10.1080/15568318.2015.1079752.
Hong, J., Shen, Q., Zhang, L., 2014. How do built-environment factors affect travel behavior? A spatial analysis at different geographic scales. Transportation 41 (3), 419–440.
Khattak, A.J., Rodriguez, D., 2005. Travel behavior in neo-traditional neighborhood developments: a case study in USA. Transp. Res. A 39, 481–500.
Lido, C., Osborne, M., Livingston, M., Thakuriah, P., Sila-Nowicka, K., 2016. Older learning engagement in the modern city. Int. J. Lifelong Educ. 35 (5), 490–508.
Lyons, G., Urry, J., 2005. Travel time use in the information age. Transp. Res. A Policy Pract. 39 (2), 257–276. http://dx.doi.org/10.1016/j.tra.2004.09.004.
Mcdonald, N.C., 2015. Are millennials really the “go-nowhere” generation? J. Am. Plan. Assoc. 81, 90–103.
Miranda, A., 2004. FIML estimation of an endogenous switching model for count data. Stata J. 4, 40–49.
Miranda, A., Rabe-Hesketh, S., 2006. Maximum likelihood estimation of endogenous switching and sample selection models for binary, ordinal, and count variables. Stata J. 6, 285–308.
Mokhtarian, P., 2009. If telecommunication is such a good substitute for travel, why does congestion continue to get worse? Transp. Lett. 1 (1), 1–17.
Mokhtarian, P., Cao, X., 2008. Examining the impacts of residential self-selection on travel behavior: a focus on methodologies. Transp. Res. B 42 (3), 204–228.
Mokhtarian, P., Tal, G., 2013. Impacts of ICT on travel behavior: a tapestry of relationships. In: Rodrigue, J., Notteboom, T., Shaw, J. (Eds.), The SAGE Handbook of Transport Studies. SAGE Publications Ltd.
Ofcom, 2015. Communications Market report: Scotland. Retrieved from. https://www.ofcom.org.uk/_data/assets/pdf_file/0022/20668/cmr_uk_2015.pdf.
Ofcom, 2016a. Communications Market Report: Scotland. Retrieved from. https://www.ofcom.org.uk/_data/assets/pdf_file/0024/43476/CMR_Scotland_2016.pdf.
Ofcom, 2016b. Connected Nations 2016: Scotland. Retrieved from. https://www.ofcom.org.uk/_data/assets/pdf_file/0035/95876/CN-Report-2016.pdf.
Park, N., Lee, H., 2012. Social implications of smartphone use: Korean college students' smartphone use and psychological well-being. Cyberpsychol. Behav. Soc. Netw. 15, 491–497.
Pew Research Center, 2014. The Web at 25 in the U.S. Retrieved from. http://www.pewinternet.org/2014/02/27/the-web-at-25-in-the-u-s/.
Pew Research Center, 2015. U.S. Smartphone Use in 2015. Retrieved from. http://www.pewinternet.org/2015/04/01/us-smartphone-use-in-2015/.
Philip, L.J., Cottrill, C., Farrington, J., 2015. ‘Two-speed’ Scotland: patterns and implications of the digital divide in contemporary Scotland. Scott. Geogr. J. 131, 148–170.
Polzin, S.E., Chu, X., Godfrey, J., 2014. The impact of millennials' travel behavior on future personal vehicle travel. Energy Strategy Rev. 5, 59–65.
Roy, P., Martinez, A.J., Miscione, G., Zuidgeest, M.H.P., van Maarseveen, M.F.A.M., 2012. Using social network analysis to profile people based on their e-communication and travel balance. J. Transp. Geogr. 24, 111–122.
Salomon, I., 1985. Telecommunications and travel: substitution or modified mobility? J. Transp. Econ. Pol. 19 (3), 219–235.
Salomon, I., 1986. Telecommunications and travel relationships: a review. Transp. Res. A 20, 223–238.
Schafer, A., 1998. The global demand for motorized mobility. Transp. Res. A Policy Pract. 32 (6), 455–477. http://dx.doi.org/10.1016/S0965-8564(98)00004-4.
Schleife, K., 2010. What really matters: regional versus individual determinants of the digital divide in Germany. Res. Policy 39, 173–185.
Schwanen, T., Kwan, M.-P., 2008. The internet, mobile phone and space-time constraints. Geoforum 39 (3), 1362–1377. http://dx.doi.org/10.1016/j.geoforum.2007.11.005.
Statista, 2016. Demographic Profile of Smartphone Owners in the United Kingdom (UK) as of 2014, by Gender. In: Retrieved from, . https://www.statista.com/statistics/497791/profile-of-smartphone-owners-by-gender-uk-survey/.
Sun, B., Zhang, T., He, Z., Wang, R., 2015. Urban spatial structure and motorization in China. J. Reg. Sci. 1–17.
Thakuriah, P., Nowicka, K.D., Paule, J., 2016. Sensing spatiotemporal patterns in urban areas: analytics and visualizations using the integrated multimedia city data platform. J. Built Environ. 42, 415–429.
The Scottish Government, 2014. Scottish Government Urban/Rural Classification 2013–2014. Edinburgh.
Tseng, Y., Knockaert, J., Verhoef, E.T., 2013. A revealed-preference study of behavioural impacts of real-time traffic information. Tranp. Res. C 30, 196–209.
Werquin, P., 2010. Recognising Non-formal and Informal Learning: Outcomes, Policies and Practices. OECD, Retrieved from Paris.
Zegras, C., 2010. The built environment and motor vehicle ownership and use: evidence from Santiago de Chile. Urban Stud. 47 (8), 1793–1817.
Zhou, Y., Wang, X., 2014. Explore the relationship between online shopping and shopping trips: an analysis with the 2009 NHTS data. Transp. Res. A 70 (Supplement C), 1–9. http://dx.doi.org/10.1016/j.tra.2014.09.014.
Zhu, P., 2013. Telecommuting, household commute and location choice. Urban Stud. 50 (12), 2441–2459. http://dx.doi.org/10.1177/0042098012474520.