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An Investigation into the Role of Information and Communication Technologies on Travel Behaviour of Working Adults and Youth

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Abstract

This thesis aims to investigate the diverse roles information and communications technologies (ICT) play in shaping individuals' mobility behaviour. In doing so, three strands of interrelated research questions are empirically analysed to better understand the use of ICT and its implications for travel among both working adults and millennials. A cross-sectional analysis is firstly performed to examine the variations in the relationships between Internet use and non-mandatory travel patterns according to household working status. By employing data from the 2005/06 Scottish Household Survey (SHS) and the two-part model, the ICT-travel relationships are found to be characterised by individual employment status and intra-household interactions, which impose different constraints on individuals' non-mandatory mobility patterns. A repeated cross-sectional analysis using the difference-in-differences (DD) estimation and the pooling of cross sections from the 2005/06 SHS data and the 2015 Integrated Multimedia City Data (iMCD) subsequently examines the evolutions in the ICT-travel relationships over time, and how temporal changes differ between the general adult population and the millennial generation. Findings suggest that the changes over time are generally characterised by diminishing complementarity and increasing substitution. Moreover, while the temporal changes for the general population are mostly found among the medium-to-heavy Internet users, for millennials, it is the light or medium-to-light users who see significant temporal changes. Finally, using the longitudinal datasets from the British Household Panel Survey (BHPS) and the Understanding Society Survey, an exploration is undertaken of the direct and indirect effects of prior experience with using ICT (as children) on millennials' current travel behaviour. The structural equation model is applied to examine the relationships between ICT use, travel choices, and environmental attitude. The longitudinal analysis finds that millennials' long-term exposure to ICT (since adolescence) may shape their current travel patterns by influencing their environmental attitudes. The findings from these analyses highlight the importance of considering the effects of personal, household, and social characteristics on the ICT-travel interactions. In addition, the research focuses on dynamic interactions and on the indirect or higher-order roles of ICT in affecting travel behaviour as well as on the implications for transport planning practices and policy making.

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Wu, G., Hong, J. and Thakuriah, P. (2017). The Role of the Internet in Shaping Young

Adults' Attitude, Travel Choices, and Sustainable Lifestyles: A Longitudinal

Perspective. In: Transportation Research Board (ed.) *TRB 96th Annual Meeting*

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Wu, G., Hong, J. and Thakuriah, P. (2015). Effect of Employment Status on the

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Authors Declaration

I declare that, except where explicit reference is made to the contribution of others, that this dissertation is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other institution.

Printed name: _____Guoqiang WU_____

Signature: _____

Chapter 1 Introduction

1.1 Background

The patterns and rhythms of modern life have become inextricably linked with transport. In order to undertake various activities for different purposes, people need to cover spatial distance, which makes travel an essential part of their daily routine. Hence, delivering an efficient and effective transport system is vital for keeping an orderly urban rhythm, which is why it has become an important component of the urban policy-making agenda. While transport greatly benefits individuals and businesses by facilitating mobility, it is also a major contributor to the current unsustainable development in urban areas, creating substantial negative externalities (e.g. congestion, pollution, noise, greenhouse gas emissions, and accidents) and internal consumption of energy. Road transport, traditionally characterised by car dependency, has been found to be the major cause of these concerns (e.g. DfT, 2010 & 2011).

A paradox, therefore, exists between the importance of developing the transport sector and the necessity to reduce the negative impacts of transport. In recent times, this paradox has motivated planners and policy-makers to adopt the planning paradigm of sustainable mobility. In current planning policy agenda for achieving sustainability in the transport sector, behavioural and technological interventions are always highlighted as they have

great potential to make a real change. The behavioural interventions, usually termed "soft" measures, are aimed at encouraging a change in individuals' travel behaviour towards more sustainable patterns, such as by minimising motorised travel and adopting eco-friendly travel modes. As for the technological interventions, they can make changes to both the supply and the demand sides of transport. On the supply side, improvements in transport systems through the use of various Information and Communication Technologies (ICT), i.e. Intelligent Transport Systems (ITS) or transport telematics, have been proven to be increasingly efficient in traffic management, pollution alleviation, energy saving, and car-dependency lowering (Banister, 2005; Thakuriah & Geers, 2013). On the demand side, increasing adoption of ICT in people's daily lives provides more opportunities and possibilities for them to participate in activities in virtual reality, which is a novel way of fulfilling activity needs traditionally met through physical travel. However, use of ICT does not necessarily imply a reduction in physical travel (Alexander et al., 2013; Audirac, 2005; Mokhtarian, 2009). Hence, there is a need to understand the effects of ICT on travel behaviour, an issue which has been widely examined in recent transport studies. Considering the significant impacts caused by ICT on both travel supply and travel demand, a digital revolution is facing the transport sector in this information age, which is leading to a new affordance of how, when, and where people can connect with other people, goods, services, and opportunities (Lyons, 2015). A transition towards more ICT-based activity patterns and accessibility has been seen, especially amongst millennials, who were born and raised in the digital era (van Wee, 2015). Therefore, within the context of this revolution, more careful and detailed research into the roles of ICT on individuals' travel behaviour is needed in order to make better use of the technological interventions and

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achieve sustainable mobility in the information age.

1.2 Research Gaps and Motivations

Since at least the 1970s, extensive research efforts have already made great contributions to understanding the relationships between ICT and activity-travel behaviour, but also posed new, further research questions and challenges. First, since individuals' mobility behaviour and their ICT use patterns are intrinsically characterised by various personal and socio-demographic attributes (e.g. gender, age, employment status, household composition), these intrinsic attributes may shape the ICT-travel relationship. For example, studies have revealed that females' daily mobility patterns are distinct from males', which is largely ascribed to the division of labour between the genders (e.g. Best & Lanzendorf, 2005; Hanson & Pratt, 1988; Madden, 1981). Furthermore, men and women are also found to have different patterns of performing Internet-based activities to meet their specific needs (e.g. Ren & Kwan, 2007; Weiser, 2004). Hence, it may not be surprising that the effects of ICT use on activity-travel behaviour differ according to gender, as discussed by Ren and Kwan (2009). Arguably, ICT use is unlikely to affect mobility behaviour evenly across different individual, household, and social groups, and thus, a generalised paradigm of ICT-travel interaction may not accurately reflect the behavioural responses to ICT adoption for specific groups. Accordingly, there is a need to investigate the specific roles of ICT on mobility behaviour among certain population segments characterised by particular personal and socio-demographic attributes, rather than by simply controlling the

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effects of those attributes in behaviour models. This would enable more accurate travel demand predictions, and the technological interventions aimed at changing travel behaviour could be more effectively implemented. Since work has been found to largely structure individuals' daily activity-travel patterns both in terms of spatial and temporal aspects (e.g. Bhat et al., 2004; Cullen & Godson, 1975; Hagerstrand, 1970), working status could be another important factor determining the ICT-travel interactions, which may need to be examined.

Another research gap is the relative lack of longitudinal analysis in examination of the ICT-travel relationships. The majority of studies have focused on the immediate effects of ICT use on individuals' travel behaviour, revealing four types of interactions in general, i.e. substitution, complementarity, modification, and neutrality, which will be elaborated in the following chapters. Due to the rapid technological evolution and the increasing penetration of ICT into daily life over time, ICT may play different roles in people's activity undertaking and trip making in different time periods. In other words, the immediate effects caused by ICT may change over time; an issue which has not been well studied. Moreover, temporal changes are also likely to occur in individuals' digital behaviour or ICT use patterns. As behavioural theories suggest, current preferences and patterns are closely related to a past history of behavioural choices (Elster, 1976; Georgescu-Roegen, 1971). It is therefore possible that individuals' travel behaviour is not only potentially affected by their current use of ICT, but also related to their past ICT experience or changes in usage over time. Although a few studies have attempted to capture the effects of changing usage of ICT on mobility (e.g. Kim & Goulias, 2004; Thulin & Vilhelmson,

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2006), the period under consideration during which the changes took place is generally short. To a large extent, the dearth of studies taking a dynamic or longitudinal point of view can be ascribed to the lack of repeated cross-sectional (RCS) or panel datasets.

In addition, existing studies tend to overlook the intermediary role that attitude plays in the ICT-travel relationships. The causal link between attitudinal factors and behaviour, which characterises classical behavioural theories, such as the Theory of Planned Behaviour (TPB), the Value-Belief-Norm (VBN) theory, and the self-perception theory, has been widely applied in explaining travel choices. Since attitudes are normally the precursor of behaviour, the ICT-induced effects on travel behaviour might be mediated by attitudes. Many studies have revealed that use of ICT can potentially influence or even shape individuals' attitudes, for example, towards the environment (Allen et al., 2013; Pickerill, 2003; Shah et al., 2007; Stokols & Montero, 2002) and politics (Bennett et al., 2008; Brunsting & Postmes, 2002; Galusky, 2003), especially among millennials who rely heavily on ICT in daily life (Yun & Chang, 2011). Hence, it is possible and rational that ICT indirectly affect travel behaviour by changing people's attitudes.

1.3 Aim, Objectives and Research Questions

This thesis attempts to make evidence-based contributions to the research on the interactions between ICT and physical mobility by addressing the research gaps identified above. In doing so, the contributions are limited to the behavioural or demand side of such

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interactions. However, the supply side in terms of the impacts of technology-enabled transport services will also be referenced in order to interpret the findings. In general, the overarching aim of this thesis is: to obtain more insight into the direct and indirect roles ICT play on mobility behaviour among different social, household, and generational groups from both cross-sectional and longitudinal perspectives.

The findings of this thesis are expected to suggest policy and planning implications for realising sustainable mobility in the information age. In order to translate this broad aim into more specific tasks, three objectives are set that represent different methodological and temporal perspectives and their relevant research questions as follows:

Objective A: Cross-sectional perspective in which the variations in the relationships between use of the Internet and non-mandatory activity-travel patterns according to household working status are examined. Household working status, which captures both individuals' employment situations and intra-household interactions, can potentially shape the ICT-travel relationships, as people facing different degrees of constraints imposed by work and intra-household interactions may have different behavioural responses to ICT adoption. Therefore, there may be a need for planners and policy-makers to obtain more accurate and holistic travel demand predictions when forming ICT-based transport policy strategies. The activity-based time-use approach is applied to answer three research questions by using a large-scale household survey database:

A1: What are the effects of the amount of time spent on the Internet on individuals' time

use for *maintenance* activities and associated travel?

A2: What are the effects of the amount of time spent on the Internet on individuals' time

use for *leisure* activities and associated travel?

A3: Do these effects vary according to different household working status? If so, to what

extent do the effects vary according to household working status?

Objective B: Repeated cross-sectional (RCS) perspective in which the temporal

evolutions in the relationships between Internet use and mobility behaviour for

non-mandatory purposes are investigated, with consideration of variations according to

generation. Due to the rapid technological advancements, individuals' ICT-usage patterns

are likely to change over time, which may lead to a temporal change in the ICT-travel

interactions. Since millennials (or the millennial generation) are distinct from preceding

generations in terms of both mobility and ICT-usage patterns, they are expected to have

different behavioural responses to the adoption of ICT, which may also evolve differently

over time. Extending the perspective of Objective A, a pseudo-longitudinal analysis is

conducted by using repeated cross-sectional data derived from two surveys to capture the

temporal dynamics in the ICT-travel relationships, both for general adults and for

millennial adults. Accordingly, three research questions will be answered:

B1: Have the relationships between Internet use and activity-travel time use for

non-mandatory (maintenance and leisure) purposes changed during the past decade?

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If so, how have such relationships changed over time?

B2: Are there any differences in terms of the ICT-travel relationships between

millennials and the general population? If so, how is millennials' travel behaviour

differently affected by use of ICT?

B3: Have the ICT-travel relationships evolved differently for millennials during the past

decade? If so, how have millennials differently changed their behavioural responses

to ICT use over time?

Objective C: Longitudinal perspective exploring the relationships between past ICT

experience and current travel behaviour for the same group of millennials and the

intermediary role their attitudes play in the relationships. As "digital natives", born and

growing up in the digital era, millennials might start to use the Internet at a young age.

Their long-term exposure to the Internet since childhood may significantly shape their

current travel patterns, which seem to be eco-friendly and sustainable, by influencing their

attitudes towards the environment. In order to capture the long-term effects of ICT use on

behaviour and attitudes, a longitudinal analysis based on the panel survey data is adopted

to mainly examine:

C1: How does past Internet usage in adolescence and changes in usage over time directly

or indirectly influence young adults' environmental attitudes, travel choices, and

pro-environmental behaviour?

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In order to obtain insights into this question, two additional issues are studied:

C2) the effects of (current) Internet use on young adults' environmental attitudes, travel choices, and pro-environmental behaviour; and

C3) the relationship between environmental attitude and travel and pro-environmental behaviour.

Clearly, the thread that links all three research objectives is temporal scale. The gradual evolution from static analysis, via trend analysis, to longitudinal analysis, which is reflected in how the research progressively tackles the objectives from A to C, implies that the research focus is extended from capturing the immediate and first-order (see Section 2.3.2) interactions between ICT and mobility, towards exploring the long-term and higher-order interactions.

1.4 Structure of the Thesis

The thesis is organised into seven chapters as follows:

Chapter 1 provides the background, motivations, and importance of this research, and specifies the research objectives and questions to be addressed.

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Chapter 2 provides comprehensive discussion of the literature relevant to this research. Three main topics are involved. Firstly, theories and concepts explaining sustainability, millennials, travel behaviour, and technology acceptance behaviour are discussed (2.1), which is followed by a policy review specifying the policy-making environment in terms of transport planning and ICT promotion (2.2). Lastly, empirical studies on activity-travel behaviour and its interactions with ICT are systematically reviewed (2.3).

Chapter 3 presents the overall research methodology and strategy applied to integrate the various components of the research process conducted in this thesis. In so doing, the sources of data utilised in the research are firstly introduced (3.1), followed by an elaboration of the main analytical techniques applied to address the research questions (3.2)

Chapter 4 addresses Objective A by employing the dataset from the Scottish Household Survey (SHS) and the techniques of the two-part model (2PM) to investigate the variations in the relationship between Internet use and activity-travel behaviour according to household working status.

Chapter 5 addresses Objective B by including a repeated cross-sectional analysis examining the temporal evolutions in the ICT-travel interactions for general and millennial adults. Based on the datasets derived from the SHS and the iMCD (Integrated Multimedia City Data) Survey, the analytical approach incorporates the difference-in-differences (DD) estimation together with the 2PM.

Chapter 6 takes a longitudinal perspective to address Objective C, seeking to identify the effects of millennials' past ICT experience on their current travel behaviour by developing a structural equation model (SEM) framework. Analysis is based on the datasets from the British Household Panel Survey (BHPS) and the Understanding Society Survey.

Chapter 7 draws the final conclusions for the thesis by highlighting the main contributions this research makes to the existing literature (7.1). The expected implications on planning and policy making are then discussed (7.2) together with the limitations that future research in this area may address (7.3).

Chapter 2 Literature Review

This chapter deals with a systematic review of the literature and aims to provide a comprehensive background for the thesis by establishing theoretical, political and empirical foundations where issues of ICT, travel behaviour and interactions between them have been understood. Given the large body of knowledge on these issues, which has been growing since at least the late 1970s, the primary scope of this chapter is to extract the major discourses, concepts, and key findings as well as the limitations predominating in existing research and policy making. Accordingly, this chapter consists of three main sections. The first section (2.1) introduces the theories and concepts that have commonly been employed to explain sustainable development, millennials, travel, and digital behaviour, providing a theoretical background for the subsequent analyses. Section 2.2 specifies the political environment in which this research lies, by reviewing policy instruments and measures commonly used in the UK's transport planning, the context of recent transport policy, and policy making for ICT promotion. The third section (2.3) discusses the empirical contributions made by existing studies on travel behaviour and its interactions with ICT, summarising and extracting their key findings by applying several taxonomies. The final section (2.4) summarises this chapter.

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2.1 Theories and Concepts: Sustainable Development, ICT, Millennials and Human Behaviour

To address empirically the research objectives set out in Chapter 1, a comprehensive review of concepts and theories related to the research topics is necessary for specifying the theoretical context in which the empirical studies lie. First, as the ultimate goal driving this research, "sustainable development" is defined with its implications for behaviour, urban development and transport planning. Second, since ICT (Information and Communication Technologies) are the key element to be empirically investigated in this research, their definitions and scopes are also discussed. Third, as an important group targeted in this research, millennials, generally referred to as those born after 1980, are introduced together with their behavioural characteristics. Subsequently, various theoretical approaches and models for explaining individuals' activity-travel behaviour are systematically reviewed. Lastly, since the Internet is seen to play an important role in changing behaviour, people's acceptance behaviour in relation to technology and technological persuasion is demonstrated theoretically.

2.1.1 Sustainable development

2.1.1.1 Concepts, principles and behavioural implications of sustainable development

The most widely accepted definition of "sustainable development" was given in the Brundtland Report (also known as *Our Common Future*) in 1987. The World Commission on Environment and Development (WCED), as it was formally called, explained "sustainable development" as the 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). This responded to the Commission's proposal of 'a global agenda for change' in the concept and practices of development (ibid.) which traditionally prioritised economic growth over all other concerns. The concept of "sustainable development" has thereafter been widely used to articulate significant shifts in 'how we relate to the world around us' and 'how we expect government to make policies that support that world view' (Strange & Bayley, 2008). At the core of sustainable development is the necessity to take the "three pillars" into account together: economy, society and environment. As for the implications of each pillar, the economic dimension of sustainable development emphasises the importance of delivering stable and enduring economic growth within the capacity of the natural environment, which was further conceptualised as "green economy" (Cato, 2009). The environmental dimension encompasses all the environmental goods, services and assets on which human life relies (Rydin, 2010), and aims to determine whether or not the

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development impacts on the surrounding environments and how the components of the environmental dimension have been considered (EEA, 2006). The social dimension is about the non-material elements of quality of life and equity, always including social well-being and security, a sense of community, the fight against poverty and the achievement of social inclusion (Rydin, 2010). There is worldwide recognition that economic growth alone is far from enough; the economic, environmental and social aspects of any actions are all interconnected. "Unsustainable" outcomes would result from considering only one of the three aspects (Strange & Bayley, 2008).

Since the concept of sustainable development was defined, there has been an increasing recognition that most of the environmental problems, such as pollution, global warming, environmental noise and loss of biodiversity, are rooted in human behaviour (Gardner & Stern, 2002; DuNann, Winter & Koger, 2004; Velk & Steg, 2007). Therefore, the sustainable development paradigm calls for changes in individuals' behaviour towards a "pro-environmental" pattern (Kollmuss & Agyeman, 2002; EEA, 2003; Velk & Steg, 2009). Pro-environmental behaviour is generally referred to as one that harms nature and the environment as little as possible, and even benefits the environment (Steg & Velk, 2009). Therefore, the adoption of such behaviour has become a key part of addressing unsustainable development and environmental issues, and 'behaviour changes will be needed to deliver sustainable development' (HM Government, 2005). Examples of pro-environmental behaviour include recycling, consumption reduction and waste minimisation. In addition, such behaviour can also relate to travel, such as a reduction in car-use and choosing to walk, cycle or take public transport.

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2.1.1.2 Urban sustainability

Population levels in urban areas have been increasing and are projected to account for 70% of the world's total population by 2050 (UN, 2009). Such rapid urbanisation is always accompanied by the loss of ecosystems, lands and social equity in order to satisfy the multiple demands of the increasing number of urban residents (Shen et al., 2011), which leads to "unsustainable" urban development. Since the release of the Brundtland Report, which called for the placing of sustainable development at the heart of urban regulations and planning rules (Vanessa, 2009), city planners and policy-makers have made great efforts to facilitate the mission of achieving sustainable urbanisation practices. The Sustainable City Conference, which was held in Rio de Janeiro in 2000, indicated that the concept of "sustainability", as applied to cities, can be defined as the ability of urban areas to 'continue to function at levels of quality of life' desired by the citizens without 'restricting the options available to the present and future generations' or generating negative impacts inside and outside the urban borders (Brebbia et al., 2000).

Similarly, "urban sustainability" is defined by the EU as the challenge to 'solve both the problems experienced within the cities themselves and the problems caused by cities' (EU, 2006). The concept of urban sustainability is often characterised by development issues such as environmental protection, proper use of resources and energy, economic vitality and diversity, individual wellbeing, community self-reliance and social cohesion (Hardoy, Mitlin & Satterthwaite, 1992; Choguill, 1996), which embody the three pillars of sustainable development. In addition, the interdependence between cities and the global environment has been highlighted in the context of urban sustainability, as even if a city

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achieves sustainability at the local level, it may not necessarily be sustainable at the global level (Alberti, 1996).

2.1.1.3 Sustainable transport/mobility

As Attard and Shiftan (2015) indicate, since urban areas are experiencing a population explosion, a crucial element for the achievement of sustainable cities is a transport system that 'is able to meet the needs for economic growth and at the same time care for the environment and people's quality of life' (Attard & Shiftan, 2015). Likewise, Banister (2005) implies that sustainable urban development depends on the city 'being the centre of vitality, opportunity and wealth' (Banister, 2005), and that the transport sector 'has a major role to play' (ibid.). Undoubtedly, transport brings about substantial benefits to individuals and businesses, such as its impacts on prices, employment and economic development at all levels (ECMT, 2000) by facilitating human activity engagement. However, it is also crystal clear that transport has greatly contributed to the current unsustainable development of urban areas by creating significant negative externalities, such as congestion, air pollution, noise, greenhouse gas emissions and accidents. The internal consumption incurred is also substantial as transport systems are responsible for between 20% and 25% of the world's energy consumption and CO_2 emissions (World Energy Council, 2007). Apart from the environmental issues, noticeable social and distributional consequences have occurred as not everyone has equal access to motorised transport or is able to afford the cost of travel (Banister, 2005). In addition, transport-induced pollution affects human health, and such negative effects particularly impact on low-income populations since they

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own few resources to protect themselves from these effects (Social Exclusion Unit, 2002). Within the context of sustainable development, the challenge facing urban transport planning is to balance the positive contributions the transport sector has made to economic growth with these negative impacts on the environment, society and public health (Attard & Shiftan, 2015; Banister, 2005).

Recognition of the transport-induced issues discussed above and a desire to address them have converged into the new paradigm of sustainable transport. While generally taken to be the expression of sustainable development in the transport sector, there is currently no consensus on a specific definition of "sustainable transport". Similar to the concept of "sustainable development", numerous definitions of "sustainable transport", and of the related term "sustainable mobility", can be found in the literature and in policy publications. Some well-accepted definitions of "sustainable transport/mobility" are summarised and shown below:

'Mobility or traffic movement that enables transport to fulfill its important economic and social functions while at the same time limiting its detrimental effect on the environment.'
(European Commission, 1992)

'[A sustainable transport system is] one in which fuel consumption, vehicle emissions, safety, congestion, and social and economic access are of such levels that they can be sustained into the indefinite future without causing great or irreparable harm to future generations of people throughout the world.' (Richardson, 1999)

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'A sustainable transport system is one that:

- *allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations;*

- *is affordable, operates fairly and efficiently, offers a choice of transport mode, and supports a competitive economy, as well as balanced regional development;*

- *limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and uses non-renewable resources at or below the rates of development of renewable substitutes, while minimizing the impact on the use of land and the generation of noise.'*

(European Union Council of Ministers of Transport, 2002)

Due to the context-specificity of sustainability (Kidd, 1992; Mitchell, 1996), it may not be strange for the lack of a single and unambiguous definition of "sustainable transport". Despite their multiplicity, however, the various definitions have all attempted to embody the "three pillars" concept in their expressions and highlight the importance of intergenerational equity, which conforms to the implications and principles of sustainable development. Among these concerns, environmental issues seem to attract more attention, with the focus on energy consumption and vehicle emissions.

The emergence and popularity of the concept of "sustainable transport/mobility" has had profound implications on transport planning, whose philosophy is now dominated by the

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need to achieve sustainability in the transport sector (Banister, 2005). The simple "predict and provide" approach, which relies on building more roadways and infrastructure to accommodate increasing volumes of motorised traffic, is incompatible with the principles of sustainable development. To crystallise the implications of sustainable mobility into planning practices, objectives are often proposed as the guidance of policies and decisions. The EU-funded PROSPECTS project, which aims to provide cities with guidance on sustainable land use and transport strategies, suggested six overarching objectives of sustainable transport: 1) economy efficiency; 2) liveable streets and neighbourhoods; 3) protection of the environment; 4) equity and social inclusion; 5) safety; 6) support of economic growth (May et al., 2001). Apart from aiming to improve physical transport systems, recent planning practices pay increasing attention to changing individuals' travel behaviour to meet the requirements of sustainable mobility, which will be further elaborated on in Section 2.2.

2.1.2 ICT (Information and Communication Technologies)

The term Information and Communication Technologies has remained in use since late 1980s (e.g. Melody et al., 1986; Silverstone et al., 1991), and its scope has been extending from the early concepts of computers and information technologies (IT). Popularisation of the term and its acronym "ICT" came with the government report regarding the use of technology in British schools in the late 1990s in which the authors stressed that:

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"…'communications' to the more familiar 'information technology'[…] to reflect the increasing role of both information and communication technologies in all aspects of society". (The Independent ICT in Schools Commission, 1997)

Thereafter, the concept became an all-encompassing phrase used in a wide range of areas. Despite the widespread usage of the phrase (ICT), however, ambiguity always exists in its meaning and definition. Such definitional difficulties are mostly attributed to the rapid development and evolution in ICT sector (Hilty et al., 2009) over time. On the one hand, any enumeration or categorisation of the sector will become outdated quickly, as new technologies appear at a quick pace. On the other hand, the general trend of ICT-based upgrades is leading to the inclusion of ICT in more goods and services, which makes the distinction between "ICT" and "non-ICT" ever more difficult (ibid.).

From the current standpoint, one of the most appealing definitions for ICT has been proposed by the OECD (Organisation for Economic Co-Operation and Development) which defines the ICT sector as a combination of three main pillars: ICT manufacturing, trade, and service industries (OECD, 2005). Manufacturing industries include the production of goods such as computers, mobile phones, and TV sets, while the trade industries comprise the wholesale of computers and other electronic equipment. In terms of the ICT services, they include web hosting, computer programming, and ICT consultancy. On the conceptual level, the OECD (2002) suggested that ICT goods "must either be intended to fulfil the function of information processing and communication by electronic means, including transmission and display, or use electronic processing to detect, measure

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and/or record physical phenomena, or to control a physical process". ICT services, on the other hand, "must be intended to enable the function of information processing and communication by electronic means" (OECD, 2002). It is clear that such definition not only focuses on the functionalities and capabilities offered by ICT, but also emphasises the role of ICT as a means of interacting with the physical world. According to the definition, ICT in current stage would include but not be restricted to:

- computers, including desktops, laptops, and tablets;

- fixed and mobile telephones, including smartphones;

- portable digital assistants (PDA);

- other communication-capable devices, e.g. TV and radio sets, music players;

- Internet, including technologies facilitating its operation, i.e. data routing, and
  accessing, e.g. Wi-Fi, fixed broadband, mobile broadband;

- other networks, e.g. local area network (LAN);

- sensing tools, e.g. closed-circuit television, satellite-based sensing, automatic traffic
  counters;

- software utilised by the hardware mentioned above, e.g. word processing or
  computer-aided design (CAD) software, Internet communicators (Skype, Viber),
  cloud computing, file storage, media streaming, social networking.

Accordingly, the meaning of ICT throughout the thesis will be in the sense described above, with a special focus on the technologies which influence activity participation and travel, i.e. the demand side, rather than the supply side of transport.

2.1.3 Millennials and digital natives

Recently, the focus of a large body of behavioural studies and policy strategies has been increasingly placed on young people, as their distinct attitudinal and behavioural characteristics have profound implications on policy making, including that for promoting sustainable development. In the US context, the young generation has been conceptualised as "millennials", "the millennial generation" or "Generation Y", which are the demographic cohort that follows "Generation X". Definitions vary as to which years of birth encompass this millennial generation. Howe and Strauss (2000) suggested that the millennial generation started with those born in 1982, which was agreed with by Huntley (2006). Weiler (2004) and Krohn (2004) defined the starting point as 1980, while Freestone and Mitchell (2004) set it as 1977. Despite the vague definition of birthdate, the millennial generation is generally characterised as being protected by both their Generation X parents and their society, and because they are driven to improve the world around them, by their virtue (Strauss & Howe, 1991). According to Howe and Strauss (2000), in the early 1980s, the US's indifference to children was reversed. Parents, government and media brought children to the forefront of national attention, which resulted in the millennials becoming the most watched-over generation in history (Keeling, 2003). The traits of millennials have been commonly identified as being special, optimistic, sheltered, confident, achieving, team-oriented, and racially and ethnically diverse (Strauss & Howe, 1991; Howe & Strauss, 2000). These traits make this generation unique and different from the members of Generation X who are always described as being independent and survival-oriented (Keeling, 2003). Therefore, Howe and Strauss (2000) predicted that

millennials would become more like the "civic-minded" G.I. generation (born between 1901 and 1924) with a strong sense of community. However, such an optimistic prediction has been questioned by scholars such as Twenge (2006) who acknowledged millennials' traits of confidence and tolerance, but also identified in them a sense of entitlement and narcissism. Twenge's (2006) study revealed that there is increasing narcissism among millennials compared to the members of preceding generations when they were teens or in their twenties. The possibility of being a "civic-minded" generation is thus questioned. Another salient trait of millennials is their tendency to delay their transitions into adulthood, which is also a reference to the trend of living with their parents for longer periods compared to their predecessors. Therefore, millennials are also labelled "the Boomerang generation" or "the Peter Pan generation" (Shaputis, 2003). Apart from the objective factors such as high housing prices, the rising cost of education and high unemployment rates, heavy parental involvement in millennials' lives could be a major cause of their delayed transitioning into adulthood (ibid.).

It seems that discussions surrounding millennials always relate to their reliance on technology. The advent of the millennial generation coincided with the development and proliferation of information and communications technologies (ICT), which has to a large extent shaped millennials' attitudes, behaviour and the ways they interact with their societies. Such ICT-induced effects on millennials even include the effects on their attitudes towards technology itself (Nimon, 2007). To the members of preceding generations, ICT, such as mobile phones and the Internet, are more likely to be tools they use to interact with other people and the world; they are useful and convenient, but may

not be essential. Millennials, however, tend to regard these technologies as an inseparable component of their daily existence 'as the clothes they wear or the food they eat' (ibid.). Computers and mobile phones are a great deal more than just tools; they are necessities supporting millennials' daily work, study, social interactions, entertainment and even travel (Huntley, 2006). Prensky (2001) proposed the concept of "digital natives" to explain millennials' high dependence on ICT. As they were born into this digital world, to some extent, millennials are 'native speakers of the digital language of computers, video games and the Internet' (Prensky, 2001). Digital natives have been immersed in technologies all their lives, which have imbued them with sophisticated knowledge and skills for adopting information technologies in various aspects of daily life. By contrast, the "digital immigrants", who were born prior to 1980, learn to adapt to the new digital environment and become fascinated by the new technologies at some later point in their lives (ibid.). Compared to the digital natives, digital immigrants are always seen to lack technological skills and fluency, and tend to retain their "accent", which can manifest itself in 'such things as turning to the Internet for information second rather than first' (Prensky, 2001). This concept has led to the common perception of a generational divide and disjuncture, which is embodied by a large body of millennial literature, highlighting the distinct technological characteristics of millennials that set them apart from their elders. However, controversies occur. Some research has revealed that not all teenagers and young adults have the familiarity with technologies which they are supposed to possess as digital natives, such as those people who find themselves on the disadvantaged side of a different digital divide as they lack access to technology (e.g. Golding, 2000; Kim & Kim, 2001; Aqili & Moghaddam, 2008). In addition, some digital immigrants have been found to be more

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"tech-savvy" than digital natives (e.g. Jenkins, 2007; Bennett, Maton & Kervin, 2008).

Therefore, it seems that the repeated "commonsensical" stories of digital natives need to be

critically rethought (Selwyn, 2009), and the potential impacts of socio-economic, cultural

and contextual factors should be considered when attempting to explain the variation in use

of technologies (Bennett, Maton & Kervin, 2008).

What seems to be undoubtedly true is that millennials' high dependence on ICT has largely

characterised their daily behaviour patterns. For instance, being reliant on the "digital

juggling" of their daily activities and commitments, millennials are described as the

"multitasking generation" (Wallis, 2006), who are accustomed to using media while

working or studying, and even using multiple media at the same time ("media

multitasking") (Foehr, 2006). As concluded by Selwyn (2009), this technology-assisted

flexibility has greatly contributed to young people's fluid lifestyles, encouraging

multiprocessing. Such flexibility in their daily lives also conveys a sense that young people

can exercise more selectivity in terms of whom they interact with, when, how, and for what

purposes (Sweeney, 2006; Selwyn, 2009). Therefore, a distinct sense of individualisation

can be strongly sensed in millennials' everyday lives. The formation of such

individualisation may also be ascribed to the personalised services and activities provided

by digital technologies, which contribute to young people's general emphasis on

customisation features when they make their choices of products and services (Sweeney,

2006). In addition to personalisation fostering, the technology-assisted flexibility has also

encouraged millennials to adopt a 'nomadic communication style' (ibid.), which enables

communication mobility and remaining in constant touch with friends or families (e.g. by

instant messaging, text messaging, cell phones and virtual social networking platforms),

and even extends their social circle. Moreover, much attention has been paid to the

technological transformation of young people's capacities for processing and learning

information. It is argued that digital natives are used to making random connections,

processing dynamic and visual information, and learning through digitally based play and

interactions (Prensky, 2001). Moreover, many empirical studies have found that millennials'

reliance on ICT significantly shapes their daily travel patterns and behaviour, which will be

expatiated in Section 2.3.

2.1.4 Understanding travel behaviour: behavioural theories and models

It has been widely accepted by scholars and policy-makers that changes in individuals'

behaviours, choices and lifestyles are the prerequisite for sustainable development (e.g.

HM Government, 1994; Dobson, 2007; UNEP, 2007; DEFRA, 2008; Hargreaves, 2011;

EEA, 2013) as current environmental challenges fundamentally result from the

unsustainable patterns of human activities (UNEP, 2007). Hence, encouraging behavioural

change has recently become the central focus of numerous environmental and sustainable

development policies. Within the UK context, attempts to promote pro-environmental

behaviour and sustainable consumption have become the key policy responses to the

challenges imposed by current unsustainable patterns (Hargreaves, 2011). Such appeals for

behavioural change have also commonly been seen in recent transport planning ideologies

which advocate shifts in individuals' travel behaviour and choices towards more

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sustainable travel futures (Prillwitz & Barr, 2011). Planners and policy-makers are paying increasing attention to interventions aimed at bringing about behavioural changes in individuals' travel patterns. Such measures are conceptualised as "soft" measures, according to the UK's policy discourse. As Prager (2012) pointed out, the prerequisite for successfully implementing interventions attempting to deliver behavioural change is to understand 'why and how behaviour change occurs and what the factors and conditions are that drive behaviours' (Prager, 2012). Likewise, McFadden (2007) indicated that a holistic understanding of individual mobility behaviour and its driving forces and determinants is essential to encourage sustainable travel patterns. Thus, this section will perform a comprehensive review of the theories and models of behaviour and behavioural change that have been widely applied to explain individual travel behaviour as well as pro-environmental behaviour.

2.1.4.1 Rational choice theory: utility maximisation

Drawing on the intellectual underpinnings of classical economics, rational choice theory is a widespread way of understanding behaviour and is deeply entrenched in the institutions and policies of modern society (Jackson, 2005). The fundamental assumption of this economics-based theory is that people always make decisions based on weighing up the pros and cons of given choices and choose the one with the highest expected net benefits or lowest expected net costs (Scott, 1999). Clearly, this theory puts the emphasis on the individual as the unit of analysis, which is referred to as "methodological individualism" (Kenneth, 1994). However, the rationality assumed in the theory has been extensively

questioned, as people are unlikely to have complete information about the benefits, costs and impacts of their actions all the time (Scott, 1999; Foley, 2004; Jackson, 2005). In addition, moral and social behaviour may also be related to where the rational choice theory is expected to address some problems. Pro-environmental behaviour is such a case since 'only a limited proportion of pro-environmental behaviour can be regarded as flowing from fundamentally self-interested value-orientations' (Jackson, 2005). Altruistic, pro-social and biospheric value orientations could explain why some pro-environmental behaviours still take place even though they generate net private costs to those who perform them (ibid.).

In transport studies, the rational choice theory is commonly referred to as "utility maximisation theory", whereby 'individuals are assumed to maximise the utility or net benefits stemming from the transportation mode selected' (Rodriguez & Joo, 2004) and 'travel is assumed to be derived from human desires ... to participate in other, non-travel activities' (Kuppam & Pendyala, 2001). Physical travel is therefore regarded as a means to an end, and a cost that needs to be minimised. Apart from the extensive criticism of its assumption of complete information acquisition, this theory's failure to acknowledge the non-instrumental benefits generated by physical travel has also been identified in transport studies (Steg & Uneken, 2002). As argued by Anable and Gatersleben (2005), 'travel may have a positive utility of its own which is not necessarily related to reaching a destination'. For instance, people who drive cars may simply do so because they like to without much real utilitarian need. In spite of the criticism, however, utility maximisation theory still provides the theoretical grounds of the modal split and trip assignment phases of the

four-step travel demand model, which is widely adopted in current transport planning and modelling practices.

2.1.4.2 Socio-psychological theories of behaviour for understanding travel and pro-environmental behaviour

The development of social psychology has offered a new perspective for behavioural studies, which typically explain human behaviour as a result of the interactions of individual mental states and immediate social situations (Baron, Byrne & Suls, 1989). In transport studies, such theories and theory models used to explain individual travel behaviour usually highlight the role of attitudinal factors in behaviour performing and choice making. Most of them focus on either the attitude-intention relationship or the norm-centred process. The classic and most common ones are elaborated as follows, together with their implications for understanding travel and pro-environmental behaviour.

• *Attitude-intention based theories: the theory of reasoned action and the theory of*

   planned behaviour

The development of the Theory of Reasoned Action (TRA) theory is supported by the expectancy-value construction, which implies that behaviour stems from individuals' beliefs about the outcomes of their behaviour and the subjective values they attach to those outcomes. As illustrated in Fig. 2-1, intention to act, in the TRA, is the direct cause of behaviour and a conscious decision to implement that action (Bohner & Wänke, 2002).

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Such intention is mediated by two constructs: attitude towards behaviour and subjective norm. The construct of attitude refers to 'the degree to which a person has a favourable or unfavourable evaluation of the behaviour in question' (Ajzen & Madden, 1986), which results from individuals' beliefs about and evaluations of behaviour outcomes. Subjective
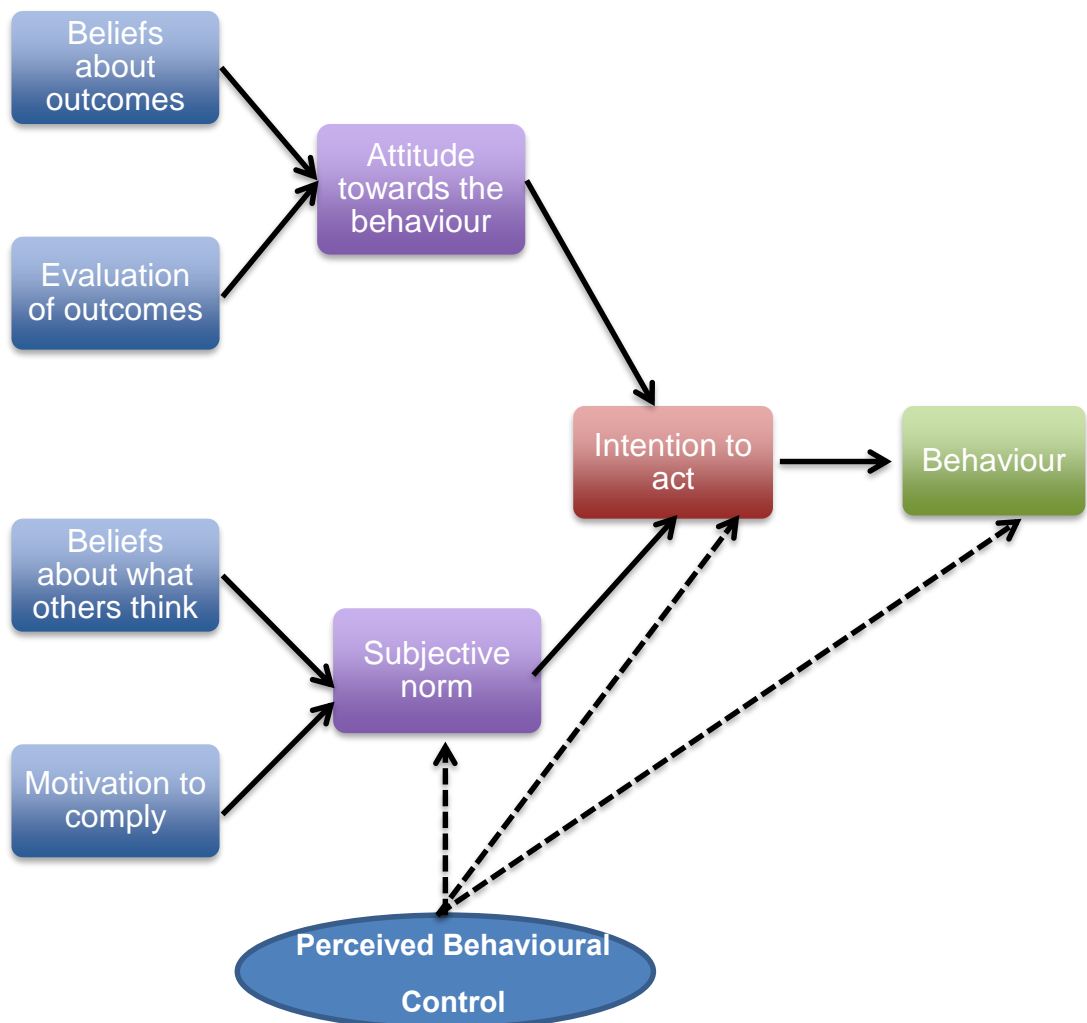
Fig. 2-1 The theory of reasoned action & theory of planned behaviour
(*From Jackson, 2005*)

norm is a 'perceived social pressure to perform or not to perform the behaviour' (ibid.), which is likewise the total product of multiplying two antecedents. The first are the person's normative beliefs and refers to how people that are important to the individual would expect him/her to behave (Ajzen & Fishbein 1980). The second is the motivation of

the person to comply with expectations. Despite its initial popularity, the TRA was subsequently criticised for being limited to the behaviour which is easily accessible, available and manageable, without considering the situations where people have incomplete volitional control over their actions (Jackson, 2005). To address such concerns, the theory of planned behaviour (TPB) was developed by Ajzen (1985 & 1991) as an extension of the TRA specifically for situations where actions are not under volitional control (Jackson, 2005). As shown in Fig. 2-1, the TPB adds a new variable to the model called "perceived behavioural control" (PBC) as an additional indicator of both intention and action. PBC is explained as 'the person's belief as to how easy or difficult performance of the behaviour is likely to be' (Ajzen & Madden, 1986), and it has two effects on aspects of the theory. It influences the intention to act as it reflects confidence to perform the behaviour (Maio & Haddock, 2010), and at the same time, it can directly influence behaviour by acting as a "check" on whether the behaviour could actually occur (Bohner & Wänke, 2002).

The TPB and TRA have proven to be successful in obtaining insights into the nature and structure of travel behaviour, especially travel choice behaviour. The constructs of attitude towards behaviour (ATT) and behavioural intention in the theory have offered a reasoned account of individuals' deliberate decisions regarding travel mode choices. The theories' validity was proven by Ajzen and Schmidt (2003), who tested the roles of past behaviour, habit and reasoned action in the choice of taking public transport. Their conclusion implies that travel mode choice is largely a reasoned action which could be influenced by interventions inducing changes in attitudes, subjective norms and perceptions of

behavioural control, whereas past travel choices may affect later behaviour only if the contexts remain relatively stable (Ajzen & Schmidt, 2003). Besides, it is well accepted that analysis of behavioural intentions and their antecedents could inform planners of people's future travel choices in early stages when their actual behaviour cannot yet be studied (Gehlert, Dziekan & Gärling, 2013). The effectiveness of introducing intention into travel demand forecasts has also been proven by a large body of studies (e.g. Heath & Gifford, 2002; Gardner, 2009; Nordlund & Westin, 2013). A meta-analytic review of studies applying the TPB to model travel mode choice (Gardner & Abraham, 2008) further suggested that intention to drive is significantly correlated to car-use behaviour, explaining a 28.1% of variance. Moreover, among the three antecedents of intention, perceived behavioural control (PBC) was identified as the strongest correlate of both intention and behaviour (ibid.). This result is consistent with the conclusions drawn in Bohner and Wänke's (2002) review, implying that the addition of PBC to the TPB could generally improve the predictive utility of the model for complex behaviour requiring planning or considerations such as mobility behaviour. Apart from public transport and car use, the TPB could also be used to effectively predict choices of active travel modes, including walking (e.g. Eves, Hoppea & McLaren, 2003; Rhodes, Brown & McIntyre, 2006) and cycling (e.g. de Bruijn et al., 2009; Gardner, 2009).

In addition, the TPB and TRA have been successfully applied to explain various types of pro-environmental behaviour, including recycling behaviour (Kaiser & Gutscher, 2003; Chan & Bishop, 2013), waste conservation (Taylor & Todd, 1995; Mannetti et al., 2004), food consumption (Harland et al., 1999) and energy use (Abrahamse, 2011; Clement,

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Henning & Osbaldiston, 2014). The theories' great success could be largely ascribed to the constructs of subjective norms and PBC developed in the TPB, which embody the altruistic and pro-social attributes of pro-environmental behaviour.

• *Norm-centred theories: value-belief-norm theory and norm-activation theory*

On the basis of social movement ideologies, Stern (2000) constructed a social-psychological model to explain pro-environmental behaviour, which is called "environmentally significant behaviour" in his research. A key premise of Stern's Value-Belief-Norm (VBN) Theory is that pro-social attitudes and personal moral norms are important predictors of pro-environmental behaviour (Stern et al., 1999), which suggests that individuals preforming environmental actions have more or less moral or altruistic reasons for doing so. The concept of personal norm, which indicates the 'moral obligation to perform or refrain from specific actions' (Schwartz & Howard, 1981), originates from Schwartz's (1977) Norm-Activation Theory (NAT), where personal norms are treated as the only direct determinants of pro-social and altruistic behaviour. Linking NAT to personal value theory and to the New Ecological Paradigm (NEP) hypothesis (Stern et al., 1999), the VBN model attempts to explain pro-environmental behaviour through a causal chain of five variables: values, NEP, AC (awareness of consequences) beliefs, AR (ascription of responsibility) beliefs, and personal norms for actions (see Fig. 2-2). The degree of acceptance of NEP is always positively related to altruistic and biospheric values and negatively related to egoistic values. Individuals' acceptance of NEP therefore positively correlates with their awareness of the (environmental) consequences of their

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actions, which in turn generates in them a stronger sense of responsibility to reduce those consequences. This chain ends with developing a personal norm that guides behaviour.

The effectiveness of VBN theory in predicting pro-environmental behaviour was validated by Stern et al. (1999), who tested the VBN model against three ecological value models

| Values | Beliefs | Norm | Behaviour |

AC= awareness of consequences
AR= ascription of responsibility
PN= personal norm
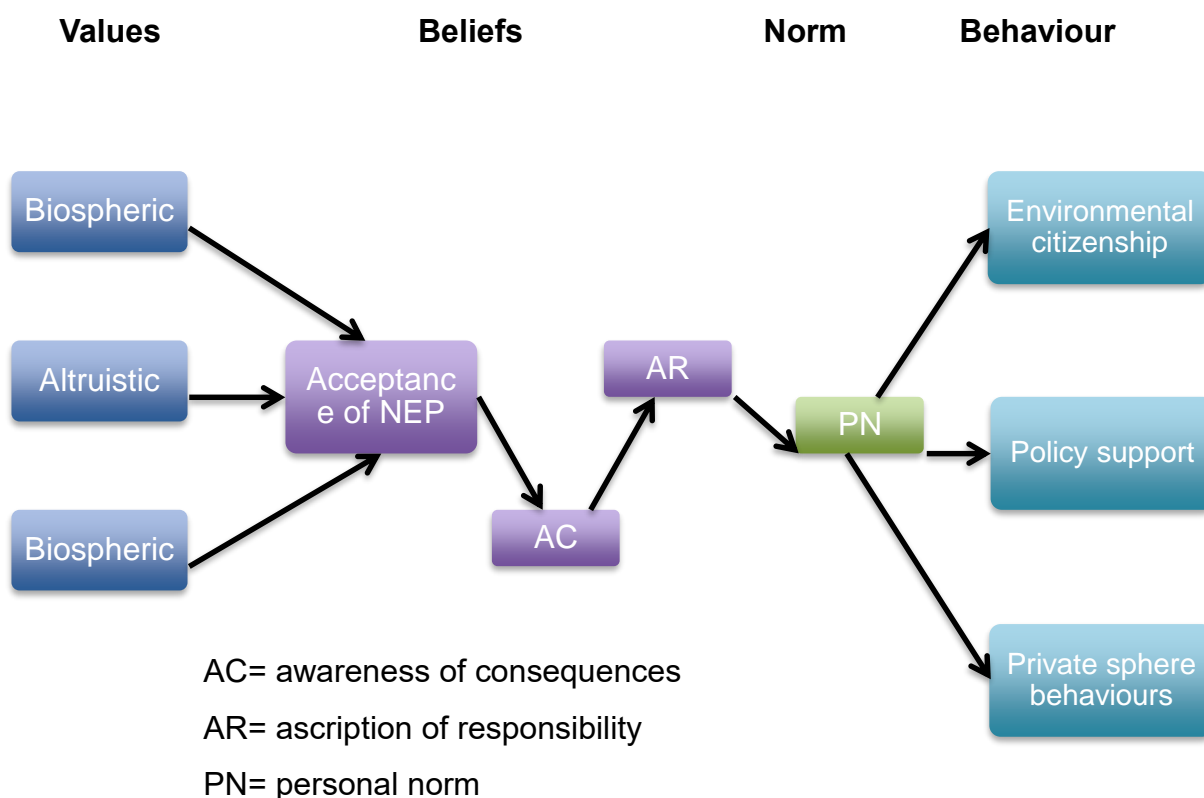
Fig.2-2 Value-Belief-Norm Mode**l**
(*From Jackson, 2005*)

related to three different indicators of pro-environmental behaviour: environmental citizenship, support for environmental policy, and reported private sphere behaviour. The results showed that of the available theories, the VBN model offered the best account of the variance in such behaviours. In transport studies, besides the VBN, norm-activation

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theory (NAT) is also commonly applied to model travel behaviour and choice. However, there have been mixed results in terms of the application of NAT and VBN theory in travel demand forecasts. For example, by applying both the TPB and NAT, Wall et al. (2008) found that both personal-normative motives and awareness of consequences had significant impacts on people's car-use intentions, and the effect of personal-normative motives was stronger. This seems to be consistent with the theoretical structure of NAT that personal norms are the immediate antecedent of altruistic actions. Likewise, Nordlund and Garvill (2003) revealed that personal norm is central in the causal chain of effects from general and environmental values, to problem awareness to willingness to reduce car use. Personal norm mediates the effects of values and specific problem awareness on willingness to cooperate in car-use reduction (Nordlund & Garvill, 2003). However, in Bamberg and Schmidt's study (2003), personal norm was found to exert no significant effect either on students' car-use intentions or on their car-use behaviour. In spite of the mixed results, the norm-centred theories have provided a new perspective, where the travel mode choice is seen as a social dilemma (Van Vugt, Meertens & Van Lange, 1995) related to individuals' decisions as to whether or not they will act to protect the environment and restrain egoistic tendencies for others' benefits (Hopper & Nielsen, 1991; Stern, Dietz & Kalof, 1993).

• *Other social-psychological theories and an integrated theoretical framework*

While the attitude-intention and norm-centred theoretical approaches have been widely

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practised in understanding mode choice, the application of many other socio-psychological behaviour theories can also be seen in explanations of travel behaviour and changes in it. For instance, cognitive dissonance theory (CDT) proposes that a person always attempts to seek consistency in his/her attitudes and beliefs in the situations where two cognitions are inconsistent or conflicting (Festinger, 1957). In pursuing cognitive consistency, the person may either change his/her attitudes towards behaviour or may seek to acquire more information to buttress the behaviour (ibid.). For example, after becoming aware of the unsustainable nature of car use, a frequent car user may desist from using the car or may seek contrary information about its benefits to come to terms with using the car. Therefore, travel behaviour studies with the application of CDT usually focus on using new information, which may be dissonant with travellers' cognition, as a means of changing their attitudes and behaviour. By examining the influences of en route information on people's travel behaviour, Kah and Lee (2016) found that during trips, those who use information technology tend to change their intended or planned behaviour, while those using "traditional" information sources (e.g. maps, road signs) are likely to actualise their intended behaviour. They therefore concluded that information technology could be viewed as dissonance-increasing information, whereas traditional information sources used during trips are more likely to be the consonance-increasing information (Kah & Lee, 2016). Another theory that is widely used to explain changes in travel choices is self-perception theory (SPT). Contrary to most behavioural theories, SPT is counterintuitive in nature as behaviour is assumed to precede attitudes, which implies that a person discovers or amends his/her attitudes by observing his/her behaviour and experience (Bem, 1972). In transport studies, the ideologies of SPT can be seen in

interventions where people are made to experience certain travel choices aimed at changing their attitudes, such as issuing free bus tickets to drivers (Fujii & Kitamura, 2003) and closing freeways to force drivers to use public transport (Fujii et al., 2001).

Such social-psychological theories for explaining individual travel behaviour vary in forms and focus, but the constructs and interactions used to develop their frameworks seem to be similar. By integrating these theoretical concepts and constructs into individuals'

Person

Influences   Habits   Psychological

                                                            costs

Infor-   Values/   Behaviour/   Behaviour

mation   Norms   Attitudes   Intentions   Behaviour   outcomes

                                                            change

Feedback

Environmental/

Situational
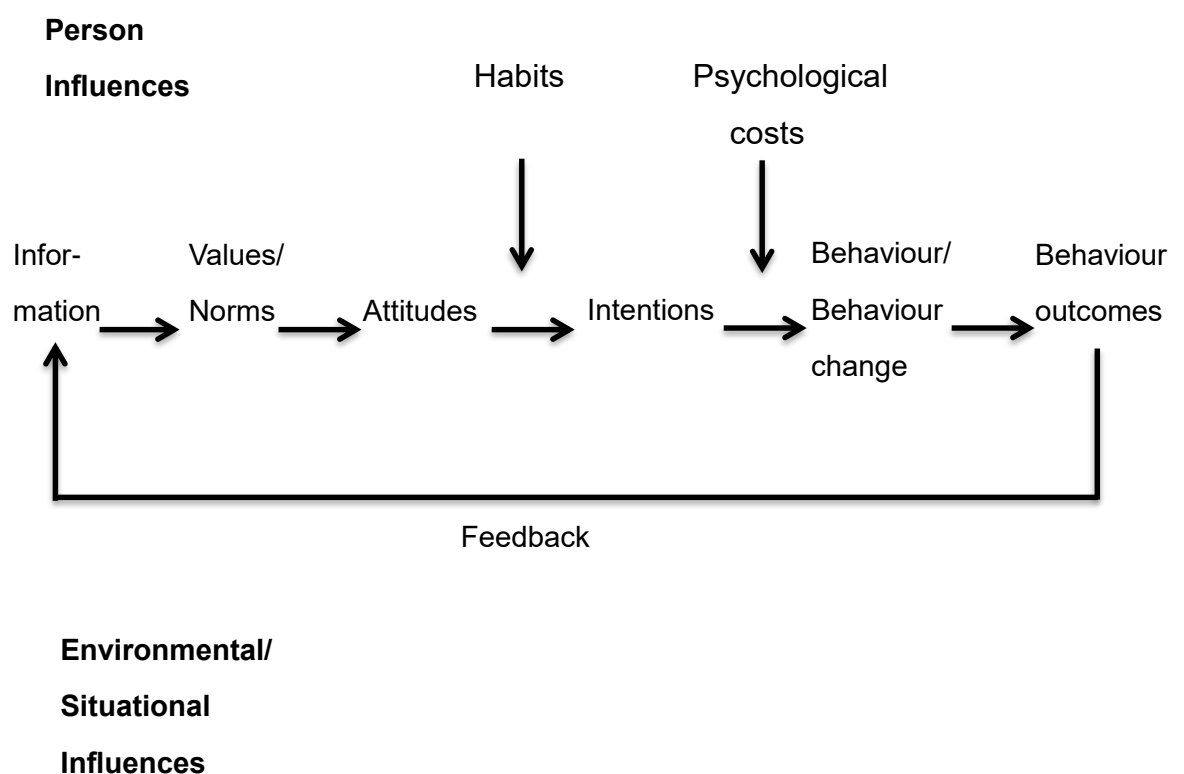
Influences

Fig. 2-3 Integrated framework identifying person factors influencing sustainable travel behaviour
(From Gehlert et al., 2013)

decision-making processes, from travel planning to actually travelling, Gehlert et al. (2013) developed a conceptual framework which identifies a set of personal factors characterising

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travel behaviour within the context of sustainability. As shown in Fig. 2-3, information on the transport systems, travel options and the consequences of choosing them is firstly acquired and processed by transport users (Gehlert, Dziekan & Gärling, 2013). Such information is then evaluated based on the norms and values users hold, which subsequently determines their attitudes towards behaviour or mode choices. If users have positive attitudes towards the behaviour outcomes, the intention to perform such behaviour would become strong. However, there are several factors which may still interfere with the final performance of behaviour. One such factor is habit; another is psychological cost, which includes planning effort, activity suppression and increased time pressure (ibid.). Lastly, the consequences of behaviour would provide feedback in terms of information acquisition for future decision-making on behaviour, and even become a source of such information.

2.1.4.3 Specific approaches to explaining travel behaviour: activity-travel theories

As Schönfelder and Axhausen (2010) pointed out, there are primarily two dimensions of travel that need to be considered for human mobility analysis. First, travel should be viewed as a transition through time and space, consisting of indivisible elements of physical movement (Hägerstrand, 1970). Second, travel is performed not for its own sake but for 'the benefits derived at the destination' where activities take place (Schönfelder & Axhausen, 2010). As travel is understood as a derived demand for activity participation, explanations of travel behaviour would be inefficient if human activity patterns were not fully considered. Therefore, the linkage between activity and travel has been made

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theoretically, and such an activity-based approach (ABA) has been the dominant focus of mobility behaviour studies since the 1970s (Jones, 1981; Beckmann, 1983). The ABA is based on Becker's (1965) classic models of time allocation to work and leisure activities, and then expanded to account for travel behaviour (Bates, 1987). The ABA views physical travel as a consequence of 'a need or demand which cannot be satisfied at the present place' (Schönfelder & Axhausen, 2010). These needs, which are commonly social, physical, physiological and cultural in nature, express themselves in a sequence of activities undertaken at different times in different places. Accordingly, this approach attempts to investigate the complex interactions between activity and travel, with the focus on the sequences or patterns of activity engagement in the whole day or longer periods of time as the analysis unit (Bhat & Koppelman, 1999). The development of ABA even led to a paradigm change within travel modelling, which traditionally had relied on trip-based analysis without considering the underlying activity demands. It is manifest that the ABA highlights two key constructs of mobility structure: temporal and spatial attributes of activity-travel behaviour.

As indicated by Bhat and Koppelman (1999), the central basis of the activity-based approach is that individuals' activity-travel patterns are a result of their time-use decisions. Given a specific period of time, such as 24 hours in a day, people always make decisions on how to allocate that time to various activities and related travel (and with whom) subject to their socio-demographic, locational, scheduling, transport and other contextual constraints (ibid.). Time-use research on human activity was enlightened by Becker's (1965) Theory of the Allocation of Time (TAT). The TAT has laid the analytical

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foundations for the studies of household production and time allocation within a household (Heckman, 2014), implying that households, like firms, need to be considered as production units (Becker, 1965). Similar to the theories of firms' behaviour in markets, a household is assumed to practise the principles of cost minimisation and utility/profit maximisation while producing commodities such as household-related services which absorb temporal and financial resources (Schönfelder & Axhausen, 2010). At the individual level, people allocate time and monetary income to a range of activities, and more specifically, they receive income from the time spent in the market (work) place, and receive utility from spending income on consuming goods or services (Gramm, 1975; Gronau, 1973). Since individuals "produce" non-market activities with the use of "inputs" including time and available market goods and services (Bhat & Koppelman, 1999), the chosen non-market activities are believed to maximise utility subject to constraints imposed by wages, time spent in the market place, and prices of consumption goods (Juster, 1990). Activities which are expected to yield greater utility are therefore given higher priority in personal time-use planning.

The above economic theories explaining activity time-use also have implications for the classification of activities, at least in terms of distinguishing between market and non-market activities. In the practices of urban planning, Reichmann (1976) further classified people's daily activities into three categories, namely, a) subsistence or work-related activities which financially support other (non-market) activities; b) maintenance activities satisfying individuals' basic physiological and psychological needs (e.g. meals, shopping, banking, personal services, medical care, professional services,

household or personal business); and c) leisure activities or recreational, social and other discretionary pursuits, such as amusements, visiting, exercise or athletics, spectator athletic events, rest and relaxation. Such a classification or similar ones imply a hierarchy in terms of time-use planning, and have been widely adopted in empirical studies on activity-travel time-use (e.g. Golob & Mcnally, 1997; Lu & Pas, 1999; Srinivasan & Bhat, 2005; Wang & Law, 2007), including the studies performed in this thesis (see Chapter 4 and 5).

As for the spatial phenomenon in activity-travel patterns, it is usually captured by spatial behaviour analysis, which has evolved from the age-old cognitive or mental mapping (Lynch, 1960) to the recently formed measures based on the concept of activity space (Golledge & Stimson, 1997). The temporal and spatial dimensions of activity-travel behaviour can also be simultaneously modelled by applying Hägerstrand's (1970) classical theory of space-time geography.

2.1.5 Acceptance behaviour on technology and technological persuasion

The proliferation of ICT (Information and Communication Technologies) applications in people's daily lives has changed their lifestyles and behaviour patterns to different degrees. Thus, the potential of ICT to promote behavioural changes has been widely acknowledged by planners and policy-makers alike, and numerous policy strategies have highlighted the role of ICT in directing shifts in individual behaviour towards better sustainability. It is therefore necessary to understand individuals' acceptance and usage of ICT from a

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theoretical perspective, and how ICT potentially change individual behaviour as persuaders.

2.1.5.1 Technology acceptance model (TAM)

One of the best known models related to technology acceptance and use is Davis's (1989) Technology acceptance model (TAM). The TAM is a theoretical model to explain and predict how users will behave with information and technology. It is considered an influential application and an extension of the theory of reasoned action (TRA). According to the TAM, the acceptability of an information system or technology is determined by two key factors: perceived usefulness and perceived ease of use. Perceived usefulness (PU) is defined as the prospective users' subjective probability that using a specific technology would enhance their job or life performance (Davis, 1989). Perceived ease of use (PEU) is explained as the degree to which the prospective users expect that using this technology would be effortless (ibid.). Both PU and PEU are influenced by various external variables; the primary external factors that are usually manifested are cultural factors, social factors including language, skills and facilitating conditions, and political factors (i.e. encouragement of technology use in politics). Based on the TRA and TPB (theory of planned behaviour), the TAM (see Fig. 2-4) suggests that actual use of an information system is determined by the behavioural intention, and the intention is determined by the prospective users' attitudes towards the use of the system and also by their perception of its

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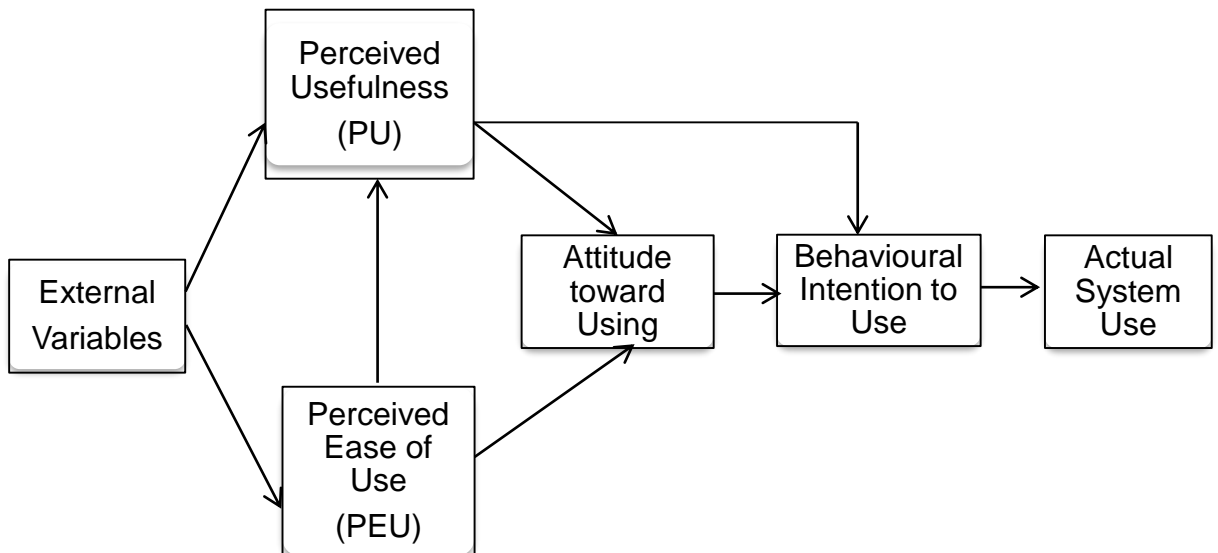
Fig. 2-4 Technology Acceptance Model
(From Davis, 1989)

utility (i.e. PU). The PU and PEU together determine users' attitudes, and the PU is

directly linked with the PEU, implying that users tend to feel that a system they find easier

to use is more useful (Dillon and Morris, 1996). The TAM appears to be able to account for

40 to 50 percent of user acceptance and has been widely applied to understand and predict

the acceptance behaviour for different types of information systems and technologies, such

as Internet usage (e.g. Lu et al., 2003; Shih, 2003; Porter & Donthu, 2006), e-learning (e.g.

Selim, 2003; Lee, Cheung & Chen, 2005), e-shopping (e.g. Pavlou, 2003; Zhou et al., 2007;

Wu & Wang, 2005), e-banking (e.g. Pikkarainen et al., 2004), and teleworking (e.g. Gupta,

Karimi & Somers, 2000; Pérez et al., 2004).

2.1.5.2 Captology: computers as persuasive technologies

The diffusion of computers, especially their functions as an interactive technology, has

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characterised their role of persuasion in changing people's attitudes and behaviour. The study and design of computers as persuasive technologies was introduced at the 1997 CHI (Computer-Human Interaction) Conference as a new research area which was called 'Captology'. Similar to human persuaders, persuasive computing technologies can potentially influence their users' attitudes and bring behavioural changes. In essence, Captology focuses on the planned persuasive effects of computer technologies, highlighting the intentionality of persuasion (Fogg, Cuellar & Danielson, 2009). Fogg (2002) proposed a framework of Functional Triad to explain how persuasive technologies influence people's attitudes and behaviour according to three computer functions — tools, media and social actors. First, as the framework suggests, computers function as persuasive tools that affect users' attitudes and behavioural changes by increasing their abilities or by making something easier to do (Tombari, Fitzpatrick, & Childress, 1985). In general, computers persuade as tools in four ways, by a) increasing self-efficacy; b) providing tailored information (with content that is pertinent to individuals' needs and contexts); c) triggering decision making; and d) simplifying or guiding people through a process facilitating behaviour adoption or change (Fogg, 2002). Second, as persuasive media, computers can change people's attitudes and behaviour by providing simulated experiences, including simulated cause-and-effect scenarios, simulated environments and simulated objects. Finally, based on the recognition that individuals form social relationships with technology (e.g. Fogg, 1997; Nass, Fogg & Moon, 1996; Marshall & Maguire, 1971), the framework suggests that computers as social actors can persuade individuals to change their attitudes and behaviour by a) providing social support; b) modelling attitudes and behaviour; and c) leveraging social rules and dynamics (Fogg,

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2002).

2.2 Policy Review: Sustainable Transport Planning, Behavioural Change and Digital Inclusion

Since this research attempts to explore the interactions between ICT and travel behaviour, which in turn can potentially bring about policy implications for promoting sustainable mobility, existing policy agendas and measures in terms of transport planning and ICT promotion need to be systematically reviewed to specify the political environment in which this study is situated. Therefore, this section demonstrates how the need for actions to mitigate the negative environmental and social impacts of transport has been recognised and addressed in the UK government's transport policy. Furthermore, the roles of ICT in policy making for achieving sustainable mobility and digital and social inclusion are also examined.

The context of the recent policy of transport planning in the UK, characterised by sustainable development and the ideology of "new realism", is firstly discussed (Section 2.2.1), together with the policy instruments currently implemented. Thereafter, Section 2.2.2 reviews the diverse "soft" measures which have been extensively practised by the government to encourage behavioural shifts towards more sustainable (travel) patterns. Following this, information technology policies aimed at facilitating digital citizenship and digital inclusion are examined in Section 2.2.3.

2.2.1 Policy context and instruments for sustainable transport planning in the UK

Traditionally, the transport planning ideologies adopted by Britain to accommodate the forecasted continuous growth in road traffic were limited to simply constructing more roadways, i.e., the concept of "predict and provide" (Goodwin, 1999). Starting in the 1970s, however, there was an increasing recognition of the negative environmental and social impacts induced by unrestricted traffic growth in urban areas, and the questionable nature of the "predict and provide" approach. The subsequent policy shift from provision for demand to demand management lifted the curtain on sustainable transport planning even though the term "sustainability" was not initially used in political rhetoric. Following the introduction of principles of sustainable development in the 1990s, the philosophy of "new realism" was created and has dominated much of the transport policy thinking over a long period. More recently, the diverse applications of ICT have been viewed as a potential facilitator for planners and policy-makers to achieve overall urban sustainability. Therefore, multiple policy initiatives of Intelligent Transport Systems (ITS) and Smart Cities have been launched by both the central and local governments to practise the "smarter" way. This section attempts to ascertain the contextual issues. Policy instruments, which have emerged in this context of sustainable planning, are also briefly introduced.

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2.2.1.1 "New realism" and sustainable development

In the early 1990s, the shift in policy-making ideology from the "predict and provide" approach to the recognition of the need for traffic demand management was conceptualised as "new realism" by Goodwin et al. (1991). This philosophy subsequently became the key theoretical support for transport policy-making in the following years. Based on the fact that 'society faces many major problems in meeting its seemingly insatiable demand for passenger travel and the movement of goods' (Goodwin et al., 1991), the "new realism" set out five principles on which policy directions can be built:

• looking at the traffic problem as a whole, not in its separate component parts;

• considering the consistency of treatment between modes (a "level playing field");

• acceptance of the impossibility of catering for all the potential desires of traffic movement;

• recognition that human factors and travellers' motivations are key elements of successful policy, so that transport policy cannot simply be technical solutions;

• differentiating the "essential" traffic from "non-essential" traffic (ibid.)

Amongst these principles, the fourth point has brought about a new policy focus on people's attitudes towards the environment and travel behaviour. The emergence of "new realism" marks a 'paradigm shift' (Headicar, 2009) in transport policy ideology, despite the fact that the comprehensive demand management approach was not quickly introduced

into policy-making by the Government (Vigar, 2002; Bulkeley & Rayner, 2003). Meanwhile, the increasing focus on sustainable development, which can be widely seen from the political rhetoric of that time, largely promoted the paradigm shift. In 1992, at the United Nations' Earth Summit in Rio de Janeiro, the British Government signed the Convention on Climate Change, requiring national greenhouse gas (GHG) emissions to be reduced to 1990 levels. Responding to this political task, the Royal Commission on Environment Pollution (RCEP) published the *Report on Transport and the Environment* in 1994, which suggested that CO_2 emissions from surface transport should be reduced to 1990 levels by 2000 and to 'no more than 80% of the 1990 level' by 2020 (RCEP, 1994). In pursuit of this target, the Commission proposed the increase of fuel duty to prompt the necessary mode shift, and a reduction in the trunk road programmes. In the same year, the revised *Planning Policy Guidance 13: Transport* (PPG13) was published focusing on local transport planning. Local authorities were required to meet the commitments of the Government's Sustainable Development Strategy to discourage motorised travel, reduce reliance on private cars, and mitigate the environmental effects caused by transport (DoE & DTp, 1994). In order to make a clear and overarching statement in response to the Government's policy on transport, the Secretary of State, Brian MacWhinney, launched a "great debate" over the future of transport policy. His speeches were collected and then published as a Consultation Document titled *Transport: The Way Ahead* (DTp, 1996). The primary concerns stated in the document were to explore the balance between economic development, environmental and personal choices, and to consider the measures to be taken if the balance needed to be shifted (ibid.). The Government's instigation of this debate was viewed as a 'genuine attempt' to resolve transport problems which were

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'increasingly conceived as being one of changing people's travel behaviour in the short, medium and long term' (Vigar, 2002).

Building on the political foundations laid by the previous practices at the policy level, the 1998 transport White Paper *A New Deal for Transport* provided a framework for an 'integrated transport strategy' focusing around the principles of sustainable development (DETR, 1998). Since the main theme of the document was "integration", this new deal needed to be practised through:

• integration within and between different types of transport;

• integration with the environment;

• integration with land use planning;

• integration with policies for education, health and wealth creation (ibid.).

As highlighted by Walton & Shaw (2003), the 1998 White Paper embodies the principles of "new realism". In addition, by indicating that 'the days of "predict and provide" were over' (DETR, 1998), it officially set traffic demand management as the key rhetorical aim of transport policy. The principles and theories proposed by the White Paper were further embodied by the *Transport Act 2000* with the emphasis on the powers provided for local authorities.

A larger policy scope can be seen in recent transport planning which inherits the "new realism" ideology. The 2011 White Paper *Creating Growth, Cutting Carbon* not only

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emphasised the necessity to resolve environmental problems induced by transport, including congestion and high GHG emissions, but also established a commitment to addressing the social exclusion issues in the context of sustainable development by encouraging 'greater local control, participation and accountability' instead of adopting previous 'one-size-fits-all solutions which ignore the specific needs' of local communities (DfT, 2011). Investment in transport infrastructure was directed to 'promote green growth' with the aim to 'build the balanced, dynamic low carbon economy' (ibid.). Moreover, the 2011 White Paper also attempted to enable more sustainable transport choices by changing people's travel behaviour. Enabling choice was epitomised by the "nudge" concept, which 'works with human behavioural tendencies to encourage "good" choices' (ibid.). Meanwhile, the 2011 Planning Policy Guidance 13 (PPG 13) added an emphasis to the key role of land use planning in delivering the Government's integrated transport strategy and facilitating sustainable development (DCLG, 2011).

2.2.1.2 A "smarter" way towards sustainability

Since their emergence, information and communication technologies (ICT) have been applied in many urban planning contexts. Not only do they have the ability to collect, analyse and store information about cities more efficiently than ever before, diverse technologies also create opportunities for planners and policy-makers to draw on this information to improve urban sustainability (e.g. EC, 2004; Murugesan & Laplante, 2011; UN-Habitat & Ericsson, 2015). In recent years, the concept of "smart cities" equipped with ICT has been taken up by many city leaders and policy-makers, resulting in a large number

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of policy publications on the topic. In the UK, these policy initiatives seem to have started the search for a "smarter" way to achieve sustainability in urban areas (Geertman et al., 2015). In the Government's *Information Economy Strategy*, the idea of "smart cities" was proposed as a key strategy to tackle the 'most pressing societal challenges [manifesting] themselves in our cities', including climate change, resource abuse and traffic congestion (HM Government, 2013). The British Standards Institution (BSI) was recently commissioned by the Department for Business, Innovation and Skills (DBIS) to develop a "Smart Cities Standards Strategy", which entails the development of policy standards aimed at promoting the uptake of the smart cities concept. According to the BSI's 2013 report, the smart cities strategy needs to bring together 'hard infrastructure, social capital including local skills and community institutions, and (digital) technologies to fuel sustainable economic development and provide an attractive environment for all' (DBIS, 2013). Five key aspects to this "smarter" approach were identified based on the principle, namely:

• a modern digital infrastructure combined with an open access approach to
 public re-useable data;

• an intelligent physical infrastructure ("smart" systems or the Internet of
  Things);

• a recognition that service delivery is improved by being citizen-centric;

• an openness to learn from others and experiment with new approaches;

• transparency of outcomes/performance (ibid.)

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As a key component of "smart cities" solutions, Intelligent Transport Systems (ITS) have gained increasing attention in transport policy-making. The potential of ITS to help realise broader transport policy goals lies in their broad applicability in the different modes of transport, and this potential is fuelled by advances in ICT and improved transport technologies (e.g. electronic tolling, GIS navigation, real-time traffic information, and dynamic traffic management). In the UK, the importance of (intelligent) technology for achieving sustainable transport has long been emphasised in many strategic policies even before ITS had even been conceptualised. For instance, the 2004 White Paper identified the role of new technologies in reducing the risk of accidents and supporting environmental protection objectives (DfT, 2004). It also set out the Government's plans for encouraging sustainable freight transport and highlighted the role of technologies as part of that agenda (ibid.). Similarly, the *Tomorrow's roads: safer for everyone*, which was published in 2000, looked beyond 2010 and identified the major potential for technological advances to make roads even safer and quicker for drivers and pedestrians (DETR, 2000a). For the first time, the *Intelligent Transport Systems (ITS): The policy framework for the roads sector* specifically set out the role of ITS in supporting delivery of the Government's transport objectives (DfT, 2005). This framework identified seven policy themes where ITS can play a pivotal role for road transport and travellers, viz:

• improving road network management (including road pricing and congestion

  alleviation);

• improving road safety;

• better travel and traveller information;

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• better public transport on the roads;

• supporting the efficiency of the road freight industry;

• reducing negative environmental impacts;

• supporting security, crime reduction and emergency planning measures.

(DfT, 2005)

2.2.1.3 Policy instruments for sustainable planning

To translate the philosophies of sustainable and "smarter" planning into practice, diverse policy instruments have been formed and implemented by both the central and local governments in Britain. These instruments can generally be categorised into four broad groups in terms of their specific targets: economic and fiscal policies, physical land use and development policies, transport management policies, and technology policies (see Headicar, 2009). The components of each policy category are illustrated in Fig. 2-5. In each case, the intentions of policy making are the same — 'to make the most efficient use of the available transport infrastructure and to use the most appropriate technology available to minimise resource consumption' (Banister, 2005) despite their different forms and focuses.

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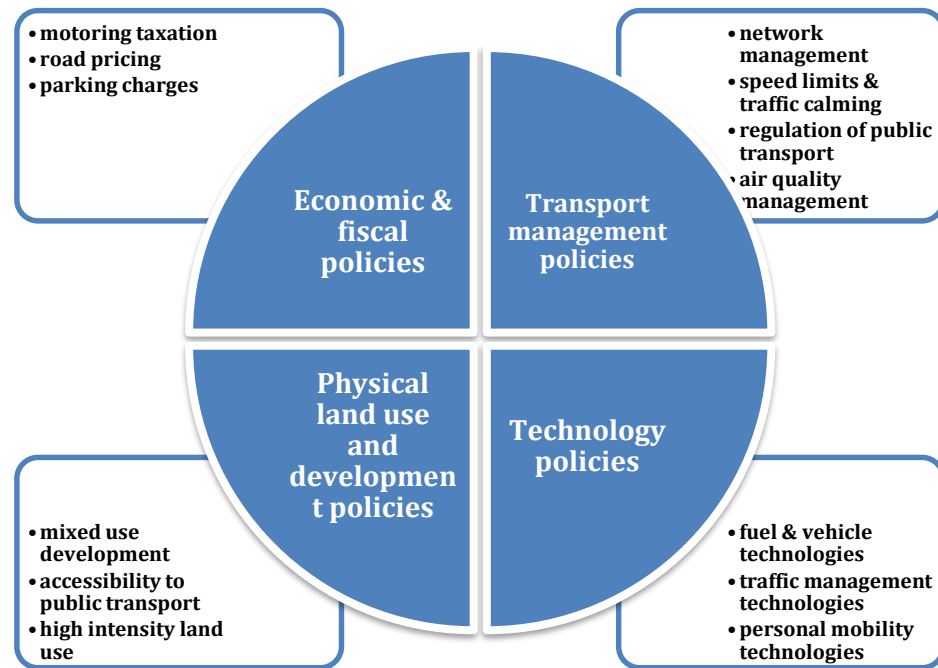
Fig. 2-5 Components of the four groups of policy instruments for sustainable transport planning

2.2.2 Policy making for behavioural change

As Banister (2005) pointed out, the effectiveness of public policy-making on sustainable development largely relies on the responsiveness of people's behaviour. Therefore, policy strategies focusing on encouraging individuals' behavioural changes have been regarded as auxiliary but also necessary approaches to achieving better sustainability. Since the early 1990s, there has been a shift of policy focus towards personal responsibility (Halpern et al., 2004), which has been reflected in the Government's attempts to facilitate people's mobility behaviour and transport mode shift. This aspiration encouragement can also be clearly seen in political attitudes towards pro-environmental behaviour, which can greatly contribute to the alleviation of environmental problems such as resource abuse and

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pollution. Due to its significant impacts on the environment, travel behaviour has been highlighted in such behaviour policies.

2.2.2.1 Promoting pro-environmental behaviour

As discussed previously, sustainable development calls for pro-environmental behaviour. According to the *Framework for pro-environmental behaviour* proposed by the Department for Environment, Food and Rural Affairs (DEFRA), the scope of pro-environmental behaviour covers six main "consumption clusters", namely, food, water, waste, travel, energy and tourism (DEFRA, 2008). Based on the six clusters, a set of 12 headline behaviour goals have been developed to identify a range of low/high impact and easy/hard behaviours. For example, the personal travel goals include using more efficient vehicles, using cars less for short trips and avoiding unnecessary flights.

The political encouragement of pro-environmental behaviour was initiated by the first UK Sustainable Development Strategy in 1994 (HM Government, 1994). Since then, the policy attempts to promote behavioural changes have centred around three approaches: 1) providing environment-related information; 2) introducing environmental regulations; 3) imposing environmental taxes and charges. Compared with the other two approaches, the first one tends to be more "soft" and favours "pull" measures rather than "push" ones. Such a "pull" approach enjoyed popularity in early policy initiatives aimed at promoting pro-environmental behaviour, with the assumption being that informing people about the environmental effects of their behaviour could automatically result in behavioural changes.

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However, the fact is that people are likely to have already considered the environmental issues and impacts caused by their behaviour. Therefore, little further change is likely to be encouraged by providing them with more information (Hobson, 2003; Darnton, 2004). Moreover, apart from awareness, individual action also depends on the perception of efficacy and the ability of individuals to act within the social and material structures they inhabit (Azjzen & Madden, 1986; Barr & Gilg, 2006). Changes in behaviour are unlikely to be achieved without addressing the material and social constraints shaping people's behaviour. DEFRA therefore recognised that 'the public are genuinely concerned about the environment, but not everyone is ready to act' (DEFRA, 2003). Thus, making people care may not necessarily lead to pro-environmental behaviour (ibid.).

It is now increasingly clear that more active and integrated approaches are needed to facilitate pro-environmental actions. By analysing the motivators of behavioural change and the different material and social constraints within which people act, the "4Es" model was developed in the report of *Securing the Future* (HM Government, 2005). This model is a tool that enables policy makers to consider a mix of interventions under four categories: encourage, enable, engage, and exemplify. Theory suggests that influencing behaviour is most effective when approaches are integrated from across these four broad areas:

- **Encouragement** includes using tax systems to provide grants for pro-environmental measures, reward schemes for pro-environmental behaviours, and social pressure (e.g. league table penalties, fines and enforcement actions).
- **Enabling** approaches are less forceful than encouragement ones, centring on making

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physical and social structures more amenable to behavioural change, such as providing

facilities, removing barriers to actions, providing viable alternatives and capacity.

• **Engaging** is about utilising the collective powers of communities to encourage

behavioural change at the individual level. Practices can be   made by community

action, personal contacts and enthusiasts, media campaigns, and using networks.

• **Exemplifying** is practised when the government leads by example and by achieving

consistency in policies (HM Government, 2005).

2.2.2.2 Changing travel behaviour

Personal travel has been the key focus of the UK Government's attempts to promote

pro-environmental behaviour. For instance, the DEFRA's *Framework for*

pro-environmental behaviours was not a policy guidance specifically targeting transport,

but travel issues were highlighted as one of the key areas where policy goals were set to

change travel behaviour (DEFRA, 2008). In addition, the desire to change travel behaviour

has also been frequently seen in recent transport policies. With the recognition that 'a clear

understanding of transport behaviour is essential', the 1998 transport White Paper (*A New*

Deal for Transport) proposed a series of measures to 'make it easier for people to choose

different and more sustainable ways of making their journeys' and to help them 'make the

changes in travel behaviour that are needed' (DETR, 1998). The 2004 White Paper (*The*

Future of Transport) indicated the importance of transport planning to provide people with

the choice of using other transport modes instead of the car and to encourage 'a change in

travel behaviour'. Measures including road pricing and technological advancements were

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proposed (DfT, 2004). The policy emphasis on behavioural change became more explicit in the 2011 transport White Paper *Creating Growth, Cutting Carbon,* which attempted to 'encourage and enable more sustainable transport choices' (DfT, 2011).

Apart from physical and fiscal instruments, another possible way of influencing individuals' travel behaviour are what have been termed "soft" measures. Although there is no precise definition of "soft" measures, they are generally perceived as the measures which 'are aimed at producing more reliable information, better informed traveller attitudes, and more benign or efficient ways of travelling' (Carins et al., 2004). Such measures, which are quite similar to the "pull" approach adopted in encouraging pro-environmental behaviour, can be used in conjunction with the traditional "hard" instruments or to generate changes in mobility behaviour with little or no change in transport systems (Headicar, 2009). Comparing them with other long-standing policy practices, Headicar (2009) summarised three aspects of recent "soft" measures which represent novelties:

• in their aims: they are fully concerned with reduction of car dependency and facilitating alternative modes;
• in the focus of their activity: on promotion and marketing instead of construction and maintenance of infrastructure or service operations;
• in their funding requirements: using revenue instead of capital spending as the investment to generate improvements in the function of transport systems.

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In 2003, the Department for Transport (DfT) commissioned a study which reviewed all the relevant evidence regarding the cost-effectiveness of soft measures, and the results were then published in the 2004 report: *Smarter Choices: changing the way we travel* (Cairns et al., 2004). The report identified ten types of "soft" travel behaviour measures: workplace and school travel plans, personalised travel plans, public transport information and marketing, car sharing and car clubs, and telecommunications possibilities, including teleworking, teleconferencing and home shopping (ibid.). Additionally, the report focused on projections for two policy scenarios over the next ten years, namely, the "high density" scenario, identifying the potential provided by a 'significant but realistic expansion of activity' (Cairns et al., 2004); and "low density" scenario, defined as a projection of the present (2003-4) levels of activity in the presence of soft measures (i.e. assuming "business as usual"). Based on all the types of measures identified above, the "high intensity" scenario predicted that the implementation of smart choices programmes would bring about a 21% reduction in peak period urban traffic (off-peak 13%); a 14% reduction in peak period non-urban traffic (off-peak 7%); and a nationwide reduction in all traffic of about 11% (ibid.).

As a result of the Smart Choices report, the DfT allocated £10m of funding for the implementation of large-scale Smarter Choice Programmes in three Sustainable Travel Towns (Darlington, Peterborough and Worcester) as a 'real-world' test of 'the smarter choices toolkit, and its efficacy in achieving travel behaviour change' (Sloman et al., 2010). The three towns were funded from 2004 to 2009 to implement a series of "soft" measures identified in the *Smarter Choices* report and the overall results of the programme were

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considered to be satisfactory. For instance, car-based trips decreased by 9% per person and car-based trip distances fell by 5-7%. By contrast, use of buses increased by 10-22% and cycling trips grew by 26-30% per person (ibid.). The "soft" measures have also been promoted in other local authority areas as part of the Smarter Choices programme, and as part of the Highway Agency's Influencing Travel Behaviour programme (Highways Agency, 2009), with varying degrees of success.

The overall success of the Smarter Choices programme suggests that people are quite receptive to this approach, providing that it is practised with other measures to "lock in" the benefits. Unlike other behaviour change policies, the programme has attempted to remove some of the material and social constraints confronting travellers; for example, by improving public transport provision, and removing some cultural barriers related to cycling. Additionally, initiatives that applied ICT to reduce the need to travel, namely, teleworking, teleconferencing and home shopping, have also contributed effectively to changing behaviour. Moreover, as Goodwin (2008) commented, a wide range of interventions could be undertaken to change behaviour if the scope for flexibility of travel behaviour is fully recognised by considering "travel choices" within a wider context, which may encompass places of residency and work, types of activities, and places people travel to, rather than just choices between transport modes (Goodwin, 2008).

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2.2.3 Policy-making for ICT promotion

2.2.3.1 Contextual issues: digital citizenship and digital divide

With the penetration of ICT into citizens' daily lives, citizenship is increasingly mediated by digital communications (Shelley et al., 2004). By assuming a secure place in civilised life, ICT 'has the potential to benefit society as a whole, and facilitate the membership and participation of individuals within society' (Mossberger et al., 2008). Therefore, digital citizenship, which is the 'norms of behaviour with regard to technology use' (Ribble et al., 2004), could potentially facilitate social inclusion (Warschauer, 2003; Mossberger et al., 2008). In the digital age, policy strategies are always directed towards encouraging people to become digital citizens with the capacity and confidence to make the most of the digital age and benefit from the diverse digital services (HM Government, 2013). In order to help policy-makers understand its complexity, Ribble et al. (2004) identified nine themes of digital citizenship:

• digital access: full electronic participation in society;

• digital commerce: electronic buying and selling of goods;

• digital communication: electronic exchange of information;

• digital literacy: process of teaching and learning about technology and the use of
   technology;

• digital etiquette: electronic standards of conduct or procedure;

• digital law: electronic responsibility for actions and deeds;

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- digital rights and responsibilities: those freedoms extended to everyone in a digital world;

- digital health and wellness: physical and psychological well-being in a digital technology world;

- digital security (self-protection): electronic precautions to guarantee safety

(Ribble et al., 2004).

While the concept of digital citizenship has been well practised in primary and secondary education and in promoting Internet use, it can also be applied in the digital mobility environment. For example, Thakuriah and Geers (2013) identified four elements of digital literacy in the mobile information environment:

- information access and use: basic skills and core competencies in locating, accessing, understanding, using and sharing information related to transport or mobility effectively and efficiently;

- comprehension of implications of use: understanding the implications of information access and use, and constructing knowledge;

- skills for protecting safety and security, and valuation of benefits versus risks: protecting oneself from risks and comparing benefits afforded by information with risks;

- comprehension of cyberspace norms: understanding the "rules" that prevail in cyberspace

(Thakuriah & Geers, 2013).

In the context of digital citizenship, digital citizens are those who use ICT regularly and

effectively (Mossberger et al., 2008). There are also non-digital citizens who are unable to access and use ICT on a regular basis for various objective and subjective reasons. The gap between digital and non-digital citizens is often referred to as the "digital divide" or "digital exclusion". The digital divide may be present across different places, socio-demographic groups, and also across different stages of the same person's life. In the UK, a large body of policy research indicates that access to ICT is patterned along the lines of socio-economic status, income, gender, age, geography, level of education, and ethnicity (e.g. MORI, 1999; National Statistics, 2000; DCLG, 2008). A lack of access to ICT has been understood as a form of social exclusion which could pose a dual threat, with 'access to ICT and the ability to use it potentially creating a new form of exclusion as well as reinforcing existing patterns of exclusion from society' (Selwyn, 2002). Accordingly, the stance of the UK Government has been firmly developed around the notions of social equity and justice for the digital age and attempting to ensure a fair information society. The Central Office of Information clearly indicated that 'In the Information Age the many must benefit, not just the few…a society of "information have-nots" would not just be unfair — it would be inefficient' (Central Office of Information, 1998). The most "digitally excluded" groups were therefore located within the "disadvantaged", "deprived" and "low income" communities (PAT15, 2000).

In a digital mobile environment, as argued by Thakuriah and Geers (2013), understanding the implications of the digital divide needs clarification in terms of *what*, *who* and *where*:

• *what*: inequality in access to the Internet, mobile devices and ICT-based fixed or

vehicular transport infrastructure and services;

• *who*: social inequity underpinnings, including income, gender, race, age, or physical and

  functional ability-based;

• *where*: country-to-country, urban-rural, and intra-urban differences

(Thakuriah & Geers, 2013).

2.2.3.2 Promoting digital inclusion

Facilitating digital inclusion, which is about 'making sure that people have the capability to use the Internet to do things that benefit them day to day' (Cabinet Office & Government Digital Service, 2014), has been prioritised in the UK's information and digital policy-making since the issue of a digital divide was first properly recognised. The initial policy actions focused on widening access to ICT with a commitment to achieving 'universal access' to the Internet by 2005. This stated commitment was later encompassed within the umbrella term 'UK Online' (DTI, 2000). The initiatives to widen access to ICT centred on establishing distributed sites of ICT access in local areas and were aimed at reducing the location- and income-induced digital exclusion, as well as at increasing community-based technological accessibility (DfEE, 2000).

As another important factor associated with the digital divide, age has also been highlighted in the Government's attempts to achieve digital inclusion. For children and young people growing up in a world in which ICT is an everyday and familiar presence, it is especially important to become informed and educated digital participants, equipped

with the capacities to be active in interpreting the world around them. Accordingly, the focus of policy has been on improving ICT access in schools and developing young people's digital literacy (Becta, 2008; DfEE, 1997). In contrast with the popular view of young people confidently inhabiting a technologically saturated society, however, older people are also considered to be at great risk of digital exclusion. The key barriers to communication inclusion, including interest, cost, skills and digital literacy, have been found to be particularly prominent among older people's experience of ICT use (Loges & Jung, 2001; Sourbati, 2004; Olphert et al., 2005). It seems that older people are not only poorer on average, but also less likely to have access to the Internet. The study into ICT access and use, which was initiated by the Department for Education and Skills (DfES), revealed that those aged 55 and over are much less likely to own or use a computer than those aged 54 and under (Russell & Stafford, 2002). Apart from having less access, in terms of attitudes towards ICT, older people are less likely to find them attractive, useful or interesting. Ofcom (Office of Communications) Consumer Panel data showed that 56% of people aged 65 and over 'voluntarily' excluded themselves from ICT use compared to the national average of 22% (Ofcom, 2006).

As the rapid revolution in ICT has been transforming the way people live and work, the Government has recognised the emergence of a 'new dynamic force' — the information economy (HM Government, 2013). The Government's *Information Economy Strategy* called for a greater focus on digital inclusion in order to:

• ensure citizens benefit from the digital age with capacity and confidence;

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- help businesses make smart use of information technology;

- underpin economic growth (ibid.).

As a response to these policy commitments, the *Government Digital Inclusion Strategy* proposed a comprehensive and integrated framework with ten actions to increase digital inclusion. The aims of the *Strategy* were to reduce the number of people lacking basic digital skills and capabilities by 25% over the following two years, address wider social issues, and close equality gaps (Cabinet Office & Government Digital Service, 2014). After reviewing previous policy attempts, the *Strategy* initially presented four main challenges that people face to going online:

- skills: ability, levels of competence and confidence in using the Internet;

- access: the ability to actually go online and connect to the Internet；

- motivation: knowing the reasons why using the Internet is a good thing；

- trust: a fear of crime, and not knowing where to start to go online (ibid.).

Ten policy actions were then generated based on the recognition that 'digital inclusion is about overcoming all of these challenges, not just one' (ibid.). Similar to previous ICT policies, providing a variety of hardware and software facilities for different individual groups with different social backgrounds was still one of the focuses of the ten actions.

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2.2.4 Summary of policy review

Transport policy in the UK has experienced a significant shift in emphasis from a physical "predict and provide" approach towards a greater focus on the responsibilities of individuals to change their own behaviour. In the context of sustainable development, a variety of policy measures have been implemented to promote pro-environmental behaviour, mainly by providing information and raising awareness. However, due to the material, social and cultural constraints within which people's behaviour takes place, individuals may not change their behaviour even though they are well informed of pro-environmental information. However, the application of "soft" policy measures in transport policy, which have been practised in the *Smarter Choices* programme in the UK, has gained a degree of success in changing individuals' travel behaviour to some extent. Apart from removing certain social and material constraints that people faced, using ICT to reduce physical travel needs also contributed to the success of the programme. The role of ICT has been further highlighted by the Government recently, particularly in terms of promoting economic growth, social inclusion and environmental protection, or, in other words, promoting sustainable development. The "smart cities" schemes and intelligent transport systems (ITS) are the representative initiatives which reflect the Government's policy strategy towards achieving sustainability via ICT. In the transport sector, ICT can not only facilitate the implementation of "hard" policy measures, such as fiscal measures, land use and traffic management measures, by enriching available resources for policy practices, but they can also potentially encourage changes in people's travel behaviour by various means, such as the provision of travel information, a reduction in travel demands,

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and facility improvement. The potential of ICT has been well recognised by planners and policy-makers. Since increasing digital inclusion is foreseeable in the future, the pursuit of sustainable mobility could be better fuelled by ICT.

2.3 Empirical Research on Travel Behaviour and Its Interactions with ICT

Following the policy and theory reviews, this section endeavours to systematically review the empirical contributions made by existing studies on travel behaviour and its interactions with ICT adoption. First, since this thesis is interested in the diversity of mobility patterns, both the internal and external factors that can potentially characterise individuals' travel behaviour are summarised and discussed. Existing findings and implications regarding the relationship between ICT adoption and travel behaviour are subsequently presented by proposing three taxonomies that extract and summarise the main ideologies characterising current studies.

2.3.1 Factors characterising travel behaviour

As a typical human behaviour, travel behaviour is intrinsically and extrinsically characterised by various factors, which, in transport studies, have been either directly examined in terms of their impacts on several travel measures like trip frequency, mode

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choice, and VMT, or controlled for modelling the effects of other interventions (e.g. ICT adoption) on travel behaviour. According to the reviewed literature, five bundles of such factors are found to have the greatest potential to influence or shape individuals' travel behaviour/patterns, i.e. socio-demographics, built environment and urban forms, intra-household interactions, attitudes and preferences, and generation. Consequently, this literature is structured accordingly. Since these factors largely determine travel behaviour, they may also affect ICT-travel relationships, as has been revealed by some studies.

2.3.1.1 Socio-demographics

Although socio-demographics are normally treated as exogenous variables whose effects are controlled in a behaviour model, they have been widely proven to play a key role in individuals' travel decisions. For instance, age may shape daily travel patterns. According to the statistics of the 2001 National Household Travel Survey (NHTS), middle-aged travellers made more daily trips and for longer distances than their younger and senior counterparts (Pucher & Renne, 2003). This is consistent with the findings of many empirical studies, which generally found that elderly people travel less than the young (e.g. Giuliano & Dargay, 2006; Newbold et al., 2005; Paez et al., 2007). In terms of mode choice, senior people are generally found to be more pro-auto than the young (e.g. Davis et al., 2012; Steg, 2005; Vega & Reynolds-Feighan, 2008). Ride sharing for non-work trips is, however, found to increase with age (e.g. Dargay & Hanly, 2004; Schwanen et al., 2004; Stead, 2001).

Gender is another important variable which is always considered in transport models. The difference in travel patterns between males and females can be roughly ascribed to the gendered division of labour, where males traditionally take the role of breadwinning, and females are mainly responsible for homemaking (Hanson & Pratt, 1988; Madden, 1981). Best & Lanzendorf (2005) found that compared with men, women made fewer journeys to work by car and more journeys for maintenance tasks, such as shopping and childcare. This finding is also confirmed by Boarnet and Sarmiento (1998) in their study of travel behaviour in California. However, the 2001 NHTS shows that such differences are becoming smaller (Pucher & Renne, 2003), especially considering the increasing participation of women in the labour market (Kitamura, 2009). Another difference in travel behaviour due to gender is that females are more likely to adopt sustainable travel patterns than males. Apart from generally travelling less often and for shorter distances than men (Moriarty & Honnery, 2005; Schwanen et al., 2002; Stead, 2001), women are also more inclined to travel by other modes instead of the car, and are more positive towards reducing the environmental impacts caused by travel (Polk, 2003 & 2004; van Acker & Witlox, 2010). Such gender differences in travel patterns also have implications for ICT-travel interactions. Having examined the role of gender in shaping individual mobility patterns and Internet usage habits (Ren & Kwan, 2007), Ren and Kwan (2009) subsequently found significantly different impacts of Internet activities on people's physical activity-travel behaviour across gender by employing multi-group structural equation modelling. Internet use for maintenance purposes has a greater effect on women's activity–travel patterns, whereas Internet use for leisure purposes affects men's physical mobility to a greater extent (Ren & Kwan, 2009).

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The impacts of individuals' employment status on their travel behaviour have also been well studied. Compared with unemployed people (non-workers), employed people (or workers) generally travel more often and over longer distances, and use the car more often (Buehler, 2011; Páez et al., 2007; Vega & Reynolds-Feighan, 2008). Since highly educated people are more likely to have specialised jobs, which are generally concentrated in high-density or central business district office parks, they are therefore more involved in long-distance travelling (commuting) with a higher car use (Dargay & Hanly, 2004; Kockelman, 1997; McNally and Kulkarni, 1997; Schwanen et al., 2002). Moreover, work largely structures individuals' activity-travel patterns. For workers, participation in other types of activities is governed by the constraints imposed by work-related activities due to the regularity and fixity of work; such constraints are often referred to as "prism" constraints (Hägerstrand, 1970). The same situation is also observed in school/college students. For workers and students, since commuting between home and workplace/school constitutes a significant part of their activity-travel patterns, and working or studying at fixed places and times substantially influences their decisions to undertake other activities, work-related activities actually act as a "peg" to characterise the daily mobility patterns of workers/students (Cullen & Godson, 1975; Bhat et al., 2004). Due to the time constraints imposed by work activities, workers always attempt to adopt some strategies to enhance their travel efficiency. One such common travel strategy is trip chaining, which is a scheduling of several activities in time and space by 'linking together work and non-work trips or two or more non-work trips' (Primerano et al., 2008). A body of studies has revealed that workers are more likely to perform trip-chaining behaviour to link work

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activities with non-work ones (e.g. shopping, picking-up/dropping-off children) during the morning or evening commute and later in the evening (e.g. Bhat & Singh, 2000; Lee et al., 2007; Yang et al., 2007; de Palma et al., 2010). Unlike workers, however, non-workers have rather flexible schedules of activity undertaking and trip making due to the absence of regular temporal and spatial fixities in their overall travel patterns. Therefore, the activity-travel patterns of non-workers are simply characterised by a series of home-based activities, and the time constraints confronting them in daily life are generally less intensive compared with those of workers (Bhat et al., 2004). Non-workers also adopt trip chaining with the aim of linking multiple non-work activities together, especially various maintenance activities, like food shopping, banking and doctor visiting (Misra & Bhat, 2000; Lee et al., 2007).

Apart from individual traits, household socio-demographics, such as household income, car ownership and presence of children in a household, have also been found to potentially shape household members' mobility patterns. Household income may influence daily travel decisions in two ways. Higher income would, in general, directly lead to more daily trips and miles travelled (Dieleman et al., 2002; Giuliano & Dargay, 2006; McNally & Kulkarni, 1997; Paez et al., 2007; Pucher & Renne, 2003), more car use and less use of other modes (Buehler 2011; McNally & Kulkarni, 1997; Ryley; 2006). On the other hand, income could indirectly manipulate individuals' travel behaviour by affecting variables that in turn directly influence travel decisions, such as car ownership in a household. Households with higher incomes generally have higher car ownership (Dargay & Hanly, 2004; Kockelman, 1997; Soltani, 2005; Whelan, 2007), which increases individuals'

propensity and frequency of trip making (Dieleman et al., 2002; Paez et al., 2007; Giuliano & Dargay, 2006) and lowers the possibilities of using other travel modes (Dieleman et al., 2002; Vega & Reynolds-Feighan, 2008). In addition, households with children also have distinct travel behaviour characteristics. These households have a stronger car dependency (Dargay & Hanly, 2004; Dieleman et al., 2002; Ryley, 2005), own but do not often use bicycles, and favour bicycle-based trips predominantly for leisure rather than subsistence purposes (Curtis & Perkins, 2006; Dieleman et al., 2002).

2.3.1.2 Built environment and urban forms

The relationships between built environment/urban forms and individuals' mobility behaviour have been well studied, primarily in terms of four dimensions: spatial density, spatial diversity, urban design, and accessibility. When modelling the effects of spatial density on travel, population and housing density is usually examined in residential neighbourhoods, while employment density is examined in activity centres. Empirical findings generally suggest that higher density is associated with lower car ownership and dependency (Cervero & Kockleman, 1997; Chatman, 2008; Frank et al., 2000; Pickrell & Schimek, 1999), more public transport use (Cervero, 2006; Frank et al., 2008; Kuby et al., 2004; Reilly & Landis, 2003; Zhang, 2004), as well as more walking and cycling (Boarnet et al., 2011; Greenwald & Boarnet, 2001; Zhang, 2004). Besides, people in dense areas also tend to travel shorter distances and spend less time on travel on average (Dargay & Hanly, 2004; Hammadou et al., 2008; Schwanen et al., 2004).

The second dimension is diversity. Spatial or land use diversity is defined as the degree to which related land uses (e.g. housing, office, retail) are located together (Litman, 2017), or the extent to which several types of land use are mixed in the same urban environment (Tanimowo, 2006). In empirical studies, different indicators have been developed to measure diversity, such as the jobs/housing ratio (Boarnet & Sarmiento, 1998; Ewing et al., 1994), the entropy index to scale the degree of balance across several land-use types within the region (Cervero & Kockelman, 1997; Frank & Pivo, 1994), and the dissimilarity index to measure the degree to which different types of land use lie within an individual's surrounding (Cervero, 2002; Kockelman, 1997). In terms of transport effects, increasing diversity could reduce car dependency (Chapman & Frank, 2004), and increase the likelihood of using public transport and slow modes (walking and cycling) (Bento et al., 2005; Cervero, 2002; Frank et al., 2008; Rajamani et al., 2003; Rielly & Landis, 2003).

Urban design also potentially shapes mobility patterns. Urban design can be generally characterised by a classification of neighbourhoods, with an intensive urban grid-like neighbourhood and a sparse suburban neighbourhood as the extremes (McNally & Kulkarni, 1997; Van Acker & Witlox, 2010). Sparse suburban neighbourhoods feature low density and diversity, high numbers of cul-de-sac street networks, and auto-centred developments, which are normally related to higher car ownership per capita and more car use (Gorham, 2002; McNally & Kulkarni, 1997). In contrast, intensive urban grid-like neighbourhoods, which are in line with the new urbanism principle, are characterised by short blocks, complete sidewalk systems, an absence of cul-de-sacs, and pedestrian-oriented designs (Ewing & Cervero, 2010). Such neo-traditional

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neighbourhoods tend to promote non-motorised travel including walking and biking (Cervero & Kockleman, 1997; Chatman, 2009; Frank et al., 2008; Greenwald & McNally, 2008).

Accessibility is the fourth dimension of built environment/urban forms characterising travel behaviour. Accessibility can be generally understood as the ability 'to reach activities or locations by means of a (combination of) travel mode(s)' (Geurs & van Wee, 2004). Studies have mostly focused on examining the effects of regional and public transport accessibilities on travel outcomes. Regional accessibility is normally measured as the proximity and connectivity of a certain site location, such as housing area, to the regional centre (e.g. CBD area) or to a specific activity location, such as office, shop, bank, school and hospital (Badoe & Miller, 2000; Litman, 2017). Findings of empirical studies reveal that sites with high accessibility are negatively associated with car ownership and car use (Boarnet et al., 2004; Cervero & Duncan, 2006; Chen et al., 2008; Kockelman, 1997; Simma & Axhausen, 2003), and positively related to travel by walking and cycling (Naess, 2005; Simma & Axhausen, 2003). As for accessible sites that are well connected by public transport, they generally promote transit-oriented travel and discourage car-oriented travel (Bento et al., 2005; Cervero, 2006; Lund et al., 2004; Kitamura et al., 1997). Furthermore, by shaping mobility patterns, accessibility can also affect the interactions between ICT use and physical travel. Hong and Thakuriah (2016) revealed that the complementary effects of Internet use on both motorised trip generation and travel distance differed according to people's residential locations. Such Internet-induced effects were found to be more significant for city dwellers than for rural residents due to the

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different levels of physical accessibility.

2.3.1.3 Intra-household interactions

There is increasing recognition that individuals are unlikely to make their activity-travel decisions in isolation from other members of their households (Srinivasan & Bhat, 2005; Ho & Mulley, 2015). Thus, activity-travel models accommodating intra-household interactions can provide more insight into individuals' mobility behaviour. The necessity to consider intra-household interactions has been demonstrated by many researchers. For instance, Golob and McNally (1997) applied a structural equation model to verify and explain the activity interactions between female and male household heads. Their results showed that the work activities of male heads determined the interactions, which implies that participation by the female heads in both maintenance and discretionary activities was significantly influenced by males' work activities. By employing trivariate ordered probit models, Scott and Kanaroglou (2002) modelled the daily activity episodes for household heads of different household types. They found that the work activities of household heads' not only influenced their own schedule of non-work activities, but their spouse's activity patterns as well. Schwanen, Ettema & Timmermans (2007) found similar results in that the decisions of out-of-home activity participation made by one partner in a household had substantial impacts on those made by the other partner.

According to the classification made by Srinivasan & Bhat (2005), there are generally four types of intra-household interactions in the context of activity-travel modelling: 1) sharing

or allocation of household maintenance responsibilities by household members; 2) joint activity participation and trip-making; 3) facilitation of activity engagement; and 4) sharing common vehicles. Among these, the allocation of activities to household members, which is a simple and efficient strategy to meet household needs under spatial, temporal and resource constraints (Ho & Mulley, 2015), has gained much research attention. For example, having modelled both in-home and out-of-home maintenance activity generation, Srinivasan and Bhat (2005) concluded that traditional gender roles still existed in household task allocations, and unemployed women were more likely to take responsibility for most of the household maintenance activities. Scott and Kanaroglou (2002) modelled the daily participation of non-work, out-of-home activities for the household heads of three different types of households – couple, non-worker; couple, one-worker; and couple, two-worker households. The results showed that traditional gender roles only existed in couple, one-worker households in which the non-workers, who were predominantly females, undertook the main responsibility for the maintenance tasks. In both the non-worker and two-worker households, however, such responsibilities were equally shared by the household heads. Furthermore, based on a comprehensive analytical framework, Srinivasan and Athuru (2005) revealed that the allocation of maintenance activities between household members was not only determined by gender and working status as household roles, income, and several types of constraints (e.g. vehicle availability, time availability, and childcare obligations) could also affect a person's allocation.

2.3.1.4 Attitudes and preferences

Recent transport studies, especially those adopting attitude-behaviour theoretical frameworks like the theory of planned behaviour (TPB) and the social-cognitive theory, increasingly include socio-psychological factors in explaining individuals' travel behaviour. The role of attitudes and preferences/perceptions is therefore highlighted in terms of shaping mobility patterns. Although attitudinal variables are measured in different ways by different researchers, in the travel behaviour domain, they are mostly formed to reflect individuals' attitudes and perceptions towards travel modes, urban forms (residential neighbourhoods), and environment. A large body of research has revealed that mode choice behaviour is largely determined by people's attitudes/perceptions towards car use and alternative modes. For example, Hiscock et al. (2002) examined the perceived psycho-social benefits of car ownership and use. They found that car users generally felt that they gained protection, autonomy and prestige from travelling by car, and car-ownership gave them "street-cred", all of which made car use more attractive than taking public transport. Such symbolic-affective motives (e.g. pleasure and social comparisons) are also found as the important determinant of using cars in other studies (e.g. Gatersleben & Uzzell, 2003; Steg et al., 2001). By forming five latent variables measuring travellers' attitudes towards safety, comfort, convenience and flexibility, and incorporating environmental considerations into their discrete mode choice model, Vredin Johansson et al. (2006) found that attitudes towards both flexibility and comfort influenced choice behaviour. Their findings suggest that flexibility is most valued by car users, whereas public transport is chosen mostly for its comfort. Such efforts to examine the influences of individual attitudes towards less tangible attributes (e.g. comfort and convenience) on

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modal choice are widely found in recent transport studies (e.g. Kuppam et al., 1999; Morikawa & Sasaki; 1998; Morikawa et al., 2002; Yanez et al., 2010), with varying results derived.

In addition to attitudes towards travel modes, attitudes towards urban forms or residential neighbourhood preferences also correlate to individuals' mobility behaviour. Boarnet & Sarmiento (1998) are among the first to highlight the issue of residential preferences, suggesting that individuals may make their residential choices according to their preferred travel options. People's choice of residential locations based on their travel preferences and the extent to which the chosen residential neighbourhoods encourage such preferences is conceptualised as residential self-selection. Recently, there has been an increasing research interest in residential self-selection as it confounds the relationships between built environment and travel behaviour and thus, presents important implications for the efficacy of land use policies for directing changes in travel behaviour (Cao, 2014). The general research question in empirical studies is to what extent the behaviour can be explained by land use characteristics alone rather than as being the result of the residential self-selection effects (Cao et al., 2009). Most studies have detected the joint impacts of urban forms and residential self-selection on travel (e.g. Boer et al., 2007; Cao et al., 2006; Chen et al., 2008; Mokhtarian & Cao, 2008).

In the emerging context of sustainable mobility, research focus is increasingly being placed on the relationship between individuals' attitudes towards the environment and their travel behaviour, particularly in terms of their travel mode decisions. Empirically, a number of

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studies have suggested that environmental attitudes, beliefs and cognitions could influence travel decisions. For instance, Nilsson and Kuller (2000) examined the impacts of attitudes and environmental knowledge on travel behaviour of citizens and public officials in the town of Lund, Sweden, and found that environmental attitudes were more effective than actual knowledge when promoting pro-environmental travel patterns. Frequency of trip making, travel habits, and acceptance of restriction policies when travelling were all significantly influenced by attitudes. Polk (2003) investigated the gender differences in terms of adapting to a sustainable transport system, revealing that women were more environmentally concerned and expressed more criticism of automobility than men, which led to their lower VMT and car use. In contrast to traditional psychological environmental studies highlighting personal variables in explaining environmental behaviour, Tanner (1999) identified several subjective and objective constraints inhibiting individuals from reducing their driving frequency. His findings revealed that in terms of subjective factors, a high sense of responsibility to preserve the environment and a low level of perceived behavioural barriers generally led to reduced driving frequency. Other types of attitudinal constructs, such as the perceived threats of environmental damages (Collins & Chambers, 2005; De Groot & Steg, 2007), perceived responsibility or feelings of guilt regarding environmental problems (Bamberg, 2007), and perceived utility of car-use reduction for alleviating the environmental problems (Steg & Sievers, 2000), were also formed and examined in terms of their influences on individuals' travel choices.

2.3.1.5 Generation

Individuals' mobility behaviour may also be shaped by the generation they belong to, and a great deal of research focus has been placed on the differences between millennials' and non-millennials' behaviour traits. Born after 1980, the millennial generation is credited as having rather different lifestyles, attitudes and behavioural patterns from previous generations (Circella et al., 2016). They also exhibit mobility patterns which are distinct from those of their predecessor cohorts. First, in terms of motorised mobility, compared with previous generations, millennials have been found to exhibit lower levels of car ownership (Dutzik et al., 2014; Lutz, 2014; O'Connell, 2013), lower rates of driver licensure (Delbosc & Currie, 2013; Raimond & Milthorpe, 2010; Schoettle & Sivak, 2014; Sivak & Schoettle, 2012), and lower car use in terms of both trip frequency and distance travelled (Dutzik et al., 2014; Le Vine & Jones, 2012; McDonald, 2015; Polzin et al., 2014). In general, they are not only less car-focused than their older counterparts, but drive less as well. Moreover, they are more likely to use public transit and active transport as well as to be multimodal (e.g. Circella et al., 2016; Dutzik et al., 2014; McDonald, 2015; TransitCenter, 2014). Additionally, they tend to embrace the advent of the sharing economy, favouring new shared mobility options, such as car-sharing, bike-sharing and on-demand ride services (e.g. Uber) (Circella et al., 2016; Garikapati et al., 2016; Lutz, 2014; O'Connell, 2013). As for overall trip making, millennials generally undertake fewer trips and travel fewer miles and minutes on a daily basis (Garikapati et al., 2016; McDonald, 2015; Polzin et al., 2014) compared with older generations. Accordingly, millennials are dubbed the "go-nowhere" generation (Buchholz & Buchholz, 2012).

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It seems that millennials' mobility patterns are more sustainable compared to those of older generations. In terms of the contributors to such patterns, dramatic socioeconomic changes have been well documented, such as economic recession, high unemployment and gasoline prices, delayed marriage and childbirth, increased college attendance and reliance on parents (Dutzik et al., 2014; McDonald, 2015; Pew Research Center, 2014), as well as millennials' distinct lifestyles and residential preferences towards city living (Nielsen, 2014; Pew Research Center, 2015; Stokes, 2013). In addition, millennials' heavy dependence on ICT in daily life also significantly reshapes their transport demands and travel behaviour (Circella et al., 2016; Lyons, 2015).

2.3.2 Dimensions characterising existing studies on the interactions between ICT use and mobility

The numerous studies dealing with ICT and mobility behaviour interactions in the field of transport research have investigated the issue from varying perspectives by applying different theories and methods. In order to get a clear understanding of current research trends and suggestions, it appears that the development of systematic taxonomies extracting and summarising the existing ideologies is necessary. This can be realised by categorising current studies in terms of three dimensions characterising their research focuses and scopes:

• Order of interactions, proposed by Gassend (1982), Salomon (1986) and Mokhtarian

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(1990) according to whether ICT adoption influences activity-travel behaviour directly (first/lower-order interactions) or indirectly, by changing the internal or external environment (second/higher-order interactions);

• Purpose of adopting ICT, which distinguishes studies in terms of whether they examine the effects of ICT applications for specific purposes (e.g. teleworking, teleshopping, tele-services), or the effects of general ICT usage (e.g. use of computer, the Internet and mobile phone) on mobility behaviour;

• Temporal perspective, namely, whether the studies are performed based on a cross-sectional point of view or longitudinal perspective.

Such taxonomies may not be all-inclusive in terms of capturing all research perspectives and methods adopted by existing studies, but they provide an efficient means of reviewing extensive studies by redefining them according to the three dimensions identified, which accommodate the properties of this research as well. The three dimensions are elaborated on in the following subsections with exemplification of relevant studies.

2.3.2.1 Orders of interactions: lower-order and higher-order interactions

The concept of orders of interactions originates from the attempts in early research to define the typology of the relationships between transportation and telecommunications. Garssend (1982) applied a systems approach to the analysis of transportation and telecommunications, identifying three types of interactions. Type I interactions are the direct effects of services provided by either mode on the relative usage of both modes,

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while Type II refers to the interactions taking place via changes in one system that influence the other. Type III interactions are mainly associated with societal changes resulting from advancement or innovations in either transportation or telecommunication systems or both. Salomon (1986) further explained Type I as first-order interactions, which include the substitution and enhancement effects telecommunications cause on travel, whilst Type II are understood as second-order interactions, which refer to situations where one system contributes to the efficiency of the other (Salomon, 1986). The higher-order interactions describe the Type III relationships, which are the indirect and long-term impacts of telecommunications on mobility patterns (Salomon, 1986; Mokhtarian, 1990).

It is manifest that the lower orders of interactions (first- and second-order) concern the direct relationships between ICT use and mobility, which in recent transport studies are generally identified as substitution, complementarity (enhancement), modification, and neutrality (Alexander et al., 2013). Although a few studies have indeed shed some light on the impacts of transport on ICT adoption, for instance, traffic congestion increases use of car phones and other mobile devices (Mokhtarian, 1990), the research focus is overwhelmingly placed on the effects of ICT use on activity-travel behaviour. The higher order interactions, on the other hand, conceptualise all the impacts of ICT on other aspects of individuals' lifestyles (e.g. attitudes and norms, residential choice, car ownership) and external environment (e.g. land-use patterns, urban forms, infrastructure provision, political context), which indirectly but significantly change mobility patterns. The occurrence of such interactions normally takes a long time as there is the need to undergo a process of changing old systems/habits and forming new ones before behavioural changes

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can be induced. The classification of interactions according to order is created to distinguish studies with different scopes and focuses. In reality, the lower- and higher-order interactions co-exist and are closely interconnected. For instance, use of the Internet may directly affect physical travel demands, while changing behaviour patterns by influencing attitudes towards the environment and lifestyles in the long term. The ultimate effect is determined by the synergy of two levels of interactions. Studies examining the two orders of interactions are discussed separately in a) and b) below, with summaries of their scopes and results.

a) Studies dealing with the lower-order interactions

As suggested before, the lower-order relationships between ICT use and mobility generally include four types of direct ICT-induced effects on activity-travel behaviour, namely, substitution, complementarity, modification, and neutrality.

• Substitution

Effects of substitution are the most popularly hypothesised interactions, especially in the early research stage. It was assumed that as use of ICT could realise communications and activity participation with lower time and space costs, the need for physical travel and face-to-face interactions would be reduced. This potential substitution is attractive for transport researchers and planners since it may facilitate sustainability in the transport sector by reducing traffic volumes, relieving traffic congestion and pollutions, and saving energy. Indeed, many studies have detected such substantive impacts caused by ICT

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adoption. For example, Hamer et al. (1991) examined the impacts of teleworking on the mobility behaviour of teleworkers and their household members, revealing that teleworking not only significantly reduced the total number of trips and peak-hour car-driving made by the teleworkers, but decreased the travel demands of their household members as well. Likewise, Balepur et al. (1998) investigated the transportation impacts of centre-based telecommuting, suggesting that both the vehicle-miles and person-miles travelled by the telecommuters were significantly fewer on telecommuting days than on non-telecommuting days. In effect, studies on teleworking or telecommuting have greatly contributed to demonstrating the substitutive impacts of ICT use on travel, which will be expatiated in the next subsections concerning the second research dimension of specific/general ICT adoption.

Deviating from the focus on teleworking, Tonn and Hemrick (2004) conducted a web survey to explore the influences of the Internet and email use on personal trip-making behaviour. They found that use of information technologies led to less driving and an overall reduction in weekly trips, though some new trips were generated. Based on a path analysis aiming to explore the relationships among telecommunications, social networks, and social activity-travel patterns, Berg et al. (2013) found the substitutive effects of ICT use on travel for social activities. A multivariate multilevel analysis was applied by Viswanathan and Goulias (2001) to examine the effects of ICT use on activity-travel time use in the Puget Sound Region. Their findings indicated that use of the Internet at home and in the workplace was significantly associated with a reduction in travel time.

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Despite the above research evidence, however, much of the early optimism about effects of substitution has reduced over time. One well-accepted explanation is that people's preferences and demands for face-to-face interactions cannot be fully replaced by ICT (Graham & Marvin, 1996). In addition, by replacing or speeding up certain physical activities, ICT may make time for other activities and related travel (Mokhtarian, 2009). Some studies on teleworking have revealed that the saved commuting time might be used by teleworkers to make other trips (e.g. Mokhtarian, 1991). In this case, it is difficult to determine if the net impact is substitution or not. Mokhtarian (2009) further summarised five reasons why ICT adoption does not always reduce travel: 1) not all activities have an ICT counterpart; 2) even when an ICT alternative exists in theory, it may not be practically feasible; 3) even when feasible, ICT is not always a desirable substitute; 4) travel carries a positive utility in its own right, not just as a means of accessing specific locations; and 5) not all uses of ICT constitute a replacement of travel.

• Complementarity

Recently, increasing research has revealed an opposite effect of ICT to that of substitution, namely, complementarity (or generation, stimulation). As suggested by Salomon (1986), such interactions can generally be distinguished according to two influence mechanisms. The first type of interactions is that ICT directly generate/stimulate travel, which is referred to as "enhancement" and belongs to the first-order interactions (Salomon, 1986). Many studies on teleshopping have detected the effects of generation which were contrary to the general hypothesis. For example, Ferrell (2004) investigated the effects of home-based teleshopping on out-of-home shopping trips and travel distance, with the results suggesting

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that teleshopping households tended to undertake more shopping trips and to chain more of their shopping trips. Farag et al. (2007) examined the relationships among the frequencies of online searching, online buying, and non-daily shopping trips, concluding that searching online positively affects the frequency of shopping trips, which in turn positively impacts on shopping online.

In terms of studies dealing with general use of ICT, Choo and Mokhtarian (2007) explored the relationship between telecommunications and transportation based on aggregated data. They concluded that telecommunications and travel are complementary to each other, namely, travel demand increases as telecommunication demand increases, and vice versa. By employing an activity-based framework, Wang and Law (2007) probed into the complex relationships among ICT use, activity engagement, and travel behaviour. Their results showed that ICT use had complementarity effects on both trip-making propensity and time used for recreation activities. In their study on the interactions between face-to-face and electronic communications in maintaining social networks, Tillema et al. (2010) found that the frequency of face-to-face contacts with relatives and friends is positively correlated with that of telecommunications by phone, email, SMS, and the Internet, pointing to a complementarity effect.

There are diverse explanations for the detection of such "enhancement" effects, which are summarised by Mokhtarian (2009) into three mechanisms working directly at the individual level. First, the contents of telecommunicated messages may directly invite travel. Second, ICT can increase people's participation in activities that involve collateral

travel by increasing accessibility to places, other people, events, information, goods and services. For example, the increased availability of interesting information about activities (e.g. shopping) and locations (e.g. stores with sales), achieved by accessing ICT applications, is likely to facilitate engagement in such activities and visits to such locations (Gottmann, 1983). Third, ICT can foster people's expectations of rapid gratification by realising instantaneous communications. Teleshopping is usually accompanied by e-shoppers' demands for the fastest shipment possible, which facilitates the just-in-time (JIT) supply chain, leading to more frequent deliveries and increased dependence on energy-intensive modes (e.g. air freight) (Matthews et al., 2001; Hesse, 2002).

Apart from the direct and immediate "enhancement" effects, there is a second type of interactions of complementarity occurring in the situation where ICT increase the efficiency of transport systems, thereby facilitating travel. Such efficiency improvements owing to the application of ICT in the transport sector are basically ascribed to the supply side. Despite their different focuses and specific suggestions, numerous studies on the impacts of ITS (Intelligent Transport System) applications, such as electronic toll collection, in-vehicle navigation systems, real-time traffic information provisions, signal timing, ramp metering, and so on (e.g. Mahmassani & Jayakrishnan, 1991; Annino & Cromley, 2005; Body, 2007; Tang & Thakuriah, 2012a) have generally highlighted the effects of speeding up and facilitating travel, or of accommodating higher volumes of travel without sacrificing efficiency (Mokhtarian, 2009). In addition, many (mobile) technologies for personal mobility, such as on-board Wi-Fi, location-based services, and travel apps of smart phones, can make travel more convenient and attractive, thereby

potentially causing effects of complementarity (e.g. Schwieterman et al., 2009; Thakuriah & Geers, 2013; Rayle et al., 2014). Mokhtarian (1990) explained all the interactions of complementarity from a broader perspective, suggesting that 'communication breeds communication'. In the picture she drew, transportation and telecommunications are treated as alternate forms of communication, hence, 'the easier it is to communicate (whether through travel or telecommunications), or the more that one or another form of communication takes place, the more that communication as a whole is stimulated' (Mokhtarian, 1990).

• Modification

Apart from substitution and complementarity, which constitute the extreme cases of interactions between ICT and mobility, ICT adoption can also have subtle effects of modification on activity-travel patterns. Instead of directly increasing/decreasing the sheer amount of travel, such effects usually change the elements characterising travel, including purposes and destination choice, mode(s) of travel, route, timing and duration.

ICT may influence people's destination choices and trip purposes in several ways. For instance, ICT can plant 'a seed with respect to a particular destination' (Mokhtarian, 2009) by disseminating information and providing guidance. Travel logs (via writings, photography, and videography) are a good case in point, which inspire numerous travellers to follow in another's footsteps and set out on a new journey. Furthermore, mobile technologies can induce real-time trip modifications by facilitating the micro-coordination of meeting times and places. For example, after receiving information conveyed by their

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colleagues already engaged in business, available taxi drivers can drive to the places where the potential passengers are waiting (Elaluf-Calderwood, 2010).

Given a specific destination, choices of travel mode(s) and route may also be affected by ICT use. In terms of their impacts on mode choice, ICT can make specific modes (e.g. public transport and cycling) attractive to travellers via widespread dissemination of promotional or affective messages, such as low fares, fast traveling, and environmental concerns (Mokhtarian, 2009). In addition, ICT can provide a variety of pre-trip information to help travellers evaluate alternative modes for travel. Location-based services, such as Google Maps, allow travellers to easily acquire route information and travel times by driving, walking, taking public transport and cycling, thereby facilitating decision-making of mode choice. Such services also encourage the choice of carpooling/rider-sharing by providing an efficient information platform (Tao & Wu, 2008; Buliung et al., 2010). Since uncertainty, such as traffic congestion, delay of departure/arrival time, change of weather, and road conditions, can be an important factor in travel decisions, the more ICT can reduce any uncertainty, the more attractive the mode will be (Mokhtarian, 2009). Moreover, the availability of or access to ICT itself can be the reason for choosing specific modes. Ettema and Verschuren (2008) carried out a stated preference survey to investigate commuters' valuations of travel time (VOT) and the impacts of ICT on them. They found that commuters who listened to music and had the propensity to participate in multiple (ICT-based) activities while traveling tended to have a lower VOT, which means travel time was valued less negatively. In this case, modes supporting multitasking while traveling, which could be greatly facilitated by ICT use (e.g. Mokhtarian et al., 2006;

Kenyon & Lyons, 2007), would be more attractive for those valuing the greater travel utility they create. As for route choice, ICT can gather dynamic information on alternative routes, facilitating selection among them and change to another. While GPS navigation and Google Maps can help travellers with pre-trip planning, Advanced Traveler information Systems (ATIS), such as variable message signs (VMS), car radio and onboard traffic data, can suggest a change in route during travel when negative situations (e.g. congestion, terrible weather, traffic accidents) are confronting travellers (Richards & McDonald, 2007; Dia & Panwai, 2007; Paz & Peeta, 2009).

Another important change in activity-travel behaviour brought about by ICT use is the increased spatial and temporal flexibility of activity engagement, which is conceptualised as fragmentation-of-activity (Alexander et al., 2013). The proliferation of nomadic ICT devices, such as laptops, smart phones and tablets, and the widespread accessibility to mobile and wireless Internet allow people to virtually participate in daily activities almost anywhere and anytime. Accordingly, ICT loosen the spatial and temporal fixity of traditional mobility patterns to a large extent. The concept of fragmentation was proposed by Couclelis (2003) to access how activities are reorganised in space and time as a result of ICT use. She described fragmentation as 'a process whereby a certain activity is divided into several smaller pieces, which are performed at different times and/or locations' (Couclelis, 2003). Clearly, there are two dimensions of fragmentation, i.e. space and time. Spatial fragmentation could be illustrated by the form of work which can now be done at home (e.g. Ory & Mokhtarian, 2006; Haddad et al., 2009), while commuting (Kenyon & Lyons, 2007), or during business trips (Laurier, 2002). Temporal fragmentation generally

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refs to the process of dividing one activity, previously performed uninterruptedly, into several subtasks that are accomplished at different times (Lenz & Nobis, 2007; Hubers et al., 2008; Ben-Elia et al., 2014).

• Neutrality

The final interaction of neutrality refers to those instances in which ICT use has no foreseeable or significant effect on activity-travel behaviour. On the one hand, the effect of neutrality could be considered as a limited case of the other three types not existing. On the other hand, it could also be the situation of net neutrality resulting from substitution and complementarity cancelling each other out (Pawlak, 2014). By using a communication diary, Mokhtarian and Meenakshisundaram (1999) gathered data on three types of communication used by citizens of Davis, California: personal meetings, transfer of an information object, and electronic communications. They applied structural equation modelling to investigate the interactions among these types of communication, finding that the relationship between personal meetings/trips and electronic communications was not significant in either direction. Hence, the effect of neutrality instead of substitution or complementarity was suggested.

Although the aforementioned four types of direct interactions between ICT and travel have been well acknowledged and proven, the research practices seems to be predominantly focused on investigating the effects of substitution or complementarity caused by ICT use. Such research tendency is largely driven by the underlying political and planning concern, i.e. the extent to which ICT use can reduce travel, which, as previously discussed, was

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overestimated in the early stage. Studies examining the substitutive or complementary effects of ICT use on travel are generally expected to yield more direct recommendations for policy strategies that are primarily aimed at reducing travel and its negative externalities in the planning context of sustainability. In addition, the evidence for the other two types of interactions (i.e. modification and neutrality) is difficult to obtain in practice, as detailed information or data about activity-travel behaviour before and after ICT use would be required to examine the rearrangements in time allocation and transport use patterns.

b) Studies dealing with the higher-order interactions

In contrast to the direct and immediate ICT-induced effects characterising the lower-order interactions, the high-order interactions describe the phenomena where ICT adoption influences individuals' activity-travel patterns indirectly and/or over long time horizons. Despite the absence of a systematic concept summarising these phenomena, much research has examined the complex and less tangible interactions from varying angles. This review identifies four groups of factors highly likely to mediate the relationship between ICT use and mobility behaviour according to suggestions made by existing studies, namely, urban form and location choices, lifestyles and time-use patterns, perceptions of travel alternatives, and market globalisation. Notably, due to the complexity of such interactions, there might be other potential factors which are detected in practice but not included in this discussion.

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• Urban form and location choices

The potential effects of ICT on land use patterns and urban form have been extensively explored by scholars and planners. As suggested by Audirac (2005), although both centrifugal and centripetal forces, imposed by the proliferation of ICT, are shaping the form of metropolises in the information age, the overall effects are facilitating the process of urban decentralisation and deconcentration, causing metropolitan areas to be 'larger, more dispersed, and less densely populated' (OTA, 1995). Since physical proximity is becoming a less binding constraint than it used to be, increasingly, residents and firms choose to settle in locations where land or labour is less costly (e.g. suburban areas, urban peripheries, and second- and third-tier cities) or amenities are better (Mokhtarian, 2009). The resulting lower density, in turn, increases the distance which travel needs to cover (van de Coevering & Schwanen, 2006). In addition, modern manufacturing and producer services, which are increasingly equipped with ICT, have also decentralised from CBDs and edge cities to second-tier metropolitan areas, as ICT infrastructures spread throughout the urban hierarchy (Beyers, 1996; Hackler, 2000; Coffey, 2000). In this case, an increase in the demand for freight mobility is expected as well (Audirac, 2005). Moreover, the growth of e-commerce and just-in-time supply chains has largely stimulated the economic agglomerations of distribution and commerce fulfilment close to airports, leading to a new urban form, "aerotropolis", characterised by 'low density, wide lanes and fast movements' (Kasarda, 2000).

Another potential ICT-fuelled contributor to urban decentralisation is teleworking, which may prompt workers to move away from their workplaces, usually located in metropolitan

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areas, to remote but cheaper residential locations. As a result, the commute frequency may decline, but the total commute distance travelled may actually be longer after telecommuting than before (Mokhtarian et al., 2004). Many studies have examined the long-term impacts of teleworking on location choices and urban form. Lund and Mokhtarian (1994) applied a simple partial equilibrium model to estimate the influences of telecommuting on vehicle distance travelled for work and residential location choices in a monocentric metropolitan area. Their results showed that telecommuting tended to facilitate changes in residential location farther from the workplaces, thereby diminishing the reduction in commute distance travelled per year owing to telecommuting. Based on the data derived from a two-year test of telecommuting by the State of California, Nilles (1991) found that 6% of the telecommuters in the study indicated that they had moved or planned to move at least 45 miles away from their workplaces since they started to telecommute. Mokhtarian et al. (2004) also implied that telecommuters tended to live farther from work on average, based on their analysis of the joint impacts of telecommuting behaviour, residential location, and one-way commute length on person miles travelled. They also proposed two possible explanations for future discussion: 1) the ability to telecommute itself prompts telecommuters to mover farther away; or 2) telecommuting is simply more attractive to people already living farther from their workplace for other reasons.

• Lifestyles and time use patterns

A vast number of studies have revealed the effects of ICT use on individuals' lifestyles, social life, and daily time-use patterns, all of which potentially shape their activity-travel

behaviour. One such aspect of ICT-facilitated change, which is increasingly being discussed in recent travel behaviour studies, is multitasking. Multitasking was defined by Kenyon (2008) as 'the simultaneous conduct of two or more activities during a given time period', embracing both natural (active) multitasking (e.g. eating while watching, working while listening to music) and time-driven (passive) multitasking prompted by time pressure (Baron, 2005). In general, multitasking, no matter whether it is performed actively or passively, can enable people to reconfigure their spatio-temporal patterns of activity participation, thereby enhancing the efficiency, quality and sense of fulfilment provided by that participation (Kenyon & Lyons, 2007). In terms of the influences of ICT use on multitasking, Nie et al. (2002) and Anderson and Tracy (2002) revealed that changes in participation in primary activities resulting from the displacement effect of Internet use might disappear when secondary or parallel activities are considered in analysis, thereby implying that greater multitasking may be enabled by the effect of Internet use. Such findings were validated by Robinson et al. (2002), who found that users of the Internet multitasked significantly more than non-users did. Kenyon (2008) further concluded two ways in which Internet use may be expected to affect multitasking: by increasing the amount of activities that can be multitasked, and by increasing the accessibility to various activities for multitasking.

Another significant contribution made by ICT use to the changes in individuals' lifestyles is its effects on social networks and interactions. Since socialising with network members accounts for the largest portion of travel in terms of distance travelled (Schlich et al., 2004; Wellman et al., 2006), social networks are crucial to understanding travel behaviour (van

den Berg et al., 2008). Similarly, Carrasco and Miller (2006) also suggested that individuals' travel behaviour is affected by their social network characteristics since these determine their propensity to undertake social activities. As the emerging ICT provide new ways of communicating within networks, the impacts of ICT use on social interactions have attracted many researchers' attention (e.g. Matei & Ball-Rokeach, 2002; Haythornthwaite & Wellman, 2002; Baym et al., 2004; Turkle, 2011; van den Berg et al., 2013). Explanations for the impacts vary, as some researchers imply that use of ICT may undermine social relations, seeing it as a solitary activity, whilst others argue that ICT play an active role in socialising processes as efficient communication tools. But one common conclusion is that ICT can potentially influence the intensity and nature of social interaction, thereby affecting activity-travel behaviour (van den Berg et al., 2013). By reviewing the findings of empirical studies, Dijst (2009) revealed that use of electronic communication means generally resulted in frequent social contacts with a relatively large social network, which in turn increases travel demand for social activities. In terms of time budget spent on social ties, its relationship with ICT use is generally presented as substitution (Dijst, 2009).

Moreover, by facilitating instant arrangement and rearrangement of activity participation, use of ICT may impact individuals' time planning horizons, which refer to the time from the taking of a decision to its actual execution. In 2005, Hjorthol (2008) conducted an analysis based on a survey with a random sample of 2,000 family respondents in Norway, revealing that by bringing the possibility of "instant action", mobile phone use led to short time planning horizons. Moreover, she also detected a significant relation between mobile

phone use, short planning horizon, and high frequency of car use. This is consistent with findings of previous studies, which indicated that car use is greater in the case of trips without advance planning than for well pre-planned trips (e.g. Jakobsson, 2004; Handy et al., 2005). Padayhag and Fukuda (2011), in contrast, found a slight positive impact of ICT use on pre-planning duration for social activities. They also identified a negative association between time planning and social activity participation, which implies that the shorter time planning is, the more social activities are undertaken.

• Perceptions of travel alternatives

In addition to directly influencing travel behaviour, use of ICT can also bring about behavioural change by changing people's perceptions of certain travel alternatives, thereby shifting mode choices. Among the attempts to promote modal shift towards more sustainable ways, the real-time provision of information has extensively been proven to be an effective tool for increasing the popularity of public transport. By modelling the relationship between perceived and actual waiting times experienced by passengers waiting for the arrival of buses at bus stations, Mishalani et al. (2006) demonstrated that passengers perceived the waiting time to be greater than the actual amount of time waited, suggesting the potential for real-time passenger information to reduce perceived waiting time and increase passenger satisfaction. Many other empirical studies have detected this positive impact on perceptions and increase in public transport use resulting from real-time information provision (e.g. Kronborg et al., 2002; Schweiger, 2003). In addition, reduction in uncertainty is another well-known contribution that real-time information provision makes to more positive perceptions of public transport. Passengers can have a better

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feeling of control and experience less stress and anxiety simply by knowing the actual departure time or time remaining until departure, thereby resulting in them becoming more reliant on the transport modes chosen (e.g. Smith et al., 1994; Sekara & Karlsson, 1997; TriMet, 2002; Schweiger, 2003). Findings from Tang and Thakuriah (2012b) further indicated that the provision of real-time transit information might serve as an intervention to break current transit non-users' travel habits, thereby increasing the mode's share of transit use.

• Market globalisation

The critical role played by ICT in driving the globalisation of markets and commerce seems to be undisputed (e.g. Sagi et al., 2004; Mokhtarian, 2009; Borghoff, 2011). A notable effect of globalisation is its generation of new travel to deliver both passengers and goods since 'ever more widespread and interconnected business relationships are developed' (Mokhtarian, 2009). From a broader perspective, it seems that economic, social, political and cultural globalisation all involve 'a continually extended practice of long-distance physical mobility' (Frandberg & Vilhelmson, 2003), as the globally extended organisations, networks and relationships need to be maintained and developed by extended mobility. Beaverstock and Budd (2013) agree with this proposition and found that ICT-enabled communication, which fuels the globalisation of markets and economic development in the digital world, stimulated more long-haul business travel, such as air travel. By empirically investigating the development of international mobility among Swedes in the context of transnationalisation and globalisation, Frandberg and Vilhelmson (2003) detected the expected trends of increased intensity, extensity and velocity in

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long-distance mobility. Moreover, their findings also indicated that the trends of globalisation not only bring about the growth of international business travel, but significantly encourage international travel related to free-time activities as well (Frandberg & Vilhelmson, 2003).

2.3.2.2 Purposes of adopting ICT: specific applications and general usage

As there are diverse ICT-based applications and services which can be used for different activity purposes in people's daily lives, some transport studies dealing with the interactions between ICT use and mobility behaviour focus on particular functional areas defined in terms of the main (tele-)activities in which individuals seek to participate; others investigate the effects of ICT adoption for general or multiple purposes on activity-travel patterns. Early studies are generally characterised by their examination of the effects of specific telecommunications (e.g. telecommuting, teleshopping) on travel, potentially assumed to be substitution. This substitution hypothesis was later increasingly questioned as the research scope broadened to be more inclusive of wider and comprehensive changes in activity-travel patterns resulting from use of ICT, which is under rapid development and penetrates daily life for more general purposes (Mokhtarian, 2002; Mokhtarian & Tal, 2013). From another aspect, more applications of ICT would lead to more varieties of tele-activities, which would in turn encourage studies on the interactions between participation in emerging tele-activities and in physical activities.

As for the applications of ICT for specific purposes whose effects on mobility have been

well documented, Mokhtarian (1990) identified eight common tele-activities where ICT are applied: communing, conferencing, shopping, banking, entertainment, education, medicine, and justice. She then examined their potential substitution nature in the transport context. Similar classifications have also been made by Andreev et al. (2010), who summarised three categories of tele-activities according to the typology of personal activity, namely, ICT-enabled mandatory activities (telecommuting and teleconferencing), ICT-enabled maintenance activities (teleshopping and tele-services), and ICT-enabled discretionary activities (tele-leisure). Amongst numerous tele-activities, telecommuting has attracted the most significant attention from the transport research community due to its great potential to reduce physical travel and relieve congestion in peak hours, hypothesised in the early stages of research. By using ICT to support productivity and communication with supervisors, colleagues and clients, employees can replace or modify the commute by working at home or at locations closer to home than the regular workplaces (Mokhtarian et al., 2004), thereby reducing their travel demands for work. Large-scale empirical studies have proven this substitution of the amount of commuting when telecommuting arrangements were implemented by measuring the number of commuting trips, vehicle miles, person miles, morning peak hours, time use for commuting, and emissions (e.g. Pendyala et al., 1991; Henderson & Mokhtarian, 1996; Koening et al., 1996; Mokhtarian & Varma, 1998; Choo et al., 2001; Lim, 2002; Glogger et al., 2008). Nevertheless, as discussed previously, the potential of substitution may be overestimated.

Similar to telecommuting, the idea of purchasing remotely and having the goods delivered has attracted researchers' interest since the 1970s (Gould & Golob, 1997). The potential for

teleshopping to substitute offline purchasing seems promising, especially considering the increasing prevalence of business-to-customer (b2c) dealing modes (Rotem & Salomon, 2007). However, as Andreev et al. (2010) pointed out, the investigation of the relationship between teleshopping and travel is more complicated than that for telecommuting as shopping activities generally consist of several elements which might be temporally and/or spatially separated: pre-purchasing, purchasing, and after-purchasing. In practice, although some studies did detect the substitutive effects of teleshopping on shopping-related travel in terms of trip frequency, time use, and distance travelled (e.g. Tacken, 1990; Luley et al., 2002; Lenz, 2003), the majority of empirical studies have showed that teleshopping did not substitute travel significantly, but might be complementary to traditional shopping activities (e.g. Gould et al., 1998; Golob & Regan, 2001; Casas et al., 2001; Mokhtarian & Salomon, 2002; Krizek & Johnson, 2003; Ferrell, 2004). Due to the complexity of shopping behaviour, Mokhtarian and Tang (2013) suggested that the conventional classification of interactions between ICT and activity-travel patterns might not always suffice to completely capture the nature of shopping activities and their association with ICT. As concluded by Mokhtarian (2004), 'e-shopping will substitute for store shopping at the margin, but both forms of shopping will probably continue to expand and co-exist'. Therefore, neither shopping type uniformly dominates the other, but interactive augmentation and modification have been seen in their relationship (Mokhtarian, 2004). In addition to shopping, there are increasing applications of ICT in other maintenance activities such as medicine (telemedicine), banking (telebanking), dealing with public authorities (tele-government and tele-voting), and other personal business (Golob, 2000). Although these tele-services seem less attractive to the transport research community

compared to telecommuting and teleshopping, several empirical studies have presented some enlightening findings. While telemedicine has generally been proven to be a good substitution for travel for medical purposes (e.g. Sjögren et al., 1999; Golob & Regan, 2001; Arnfalk, 2002), telebanking tends to have mixed effects on travel both in substitution (e.g. Handy & Yantis, 1997) and complementarity (e.g. Hjorthol & Gripsrud, 2009) forms.

Despite leisure activities occupying most of the personal (non-work) time, the impacts of tele-leisure remain the least understudied issue in tele-activities studies (Andreev et al., 2007). For one thing, transport researchers generally consider the impacts of ICT on leisure activities less important than those on mandatory (e.g. work) and maintenance (e.g. shopping) activities, especially in their potential to resolve transport-related problems such as congestion, environmental pollution, and land use (Andreev et al., 2010). For another, the nature of the concept of "leisure" and its boundaries with other activities are hard to define, and depend heavily on subjective perceptions (Mokhtarian et al., 2006). However, Salomon (1986) indicated that in situations with tight space-time budgets, tele-leisure at home might substitute travel for leisure purposes. Some research practices show agreement with this proposition, suggesting that in-home leisure activities facilitated by ICT can potentially substitute out-of-home leisure and/or reduce travel for that purpose (e.g. Peng and Zhang, 2008; Hjorthol & Gripsrud, 2009). But such substitution was found to be insignificant in other studies, which even revealed effects of complementarity (e.g. Handy & Yantis, 1997; Senbil & Kitamura, 2003).

Instead of focusing on ICT adoption for specific purposes, a large body of research has

examined the impacts of ICT use on individuals' mobility behaviour with general or multiple activity purposes. Since ICT have been advancing at an astonishing speed and have penetrated almost every aspect of daily life, people's activity-travel patterns have been largely reshaped by their use of or even reliance on ICT. This reshaping has been most commonly seen and best proven as a result of using computers, the Internet, and mobile technologies for a wide range of activity purposes. The findings of these studies have revealed far more complicated interactions between ICT and mobility than simple substitution or complementarity effects caused by ICT adoption on travel for a specific activity purpose. This verifies the 'cautious conclusion' made by Salomon's (1986) early study that 'travel patterns will be modified rather than reduced' as a consequence of using telecommunications in daily life (ibid.). On the other hand, the increasing advancement and proliferation of ICT have generated a wider variety of tele-services/activities to be adopted in order to satisfy individuals' various needs, which in turn has bred studies exploring the impacts of emerging ICT applications on mobility patterns. The increasing focus on the effects of location-based services (LBS) on ridesharing is a case in point (e.g. Gidofalvi & Pedersen, 2007; Tao & Wu, 2008; Lalos et al., 2009).

2.3.2.3 Temporal perspective: cross-sectional and longitudinal analysis

Based on data collected at a specific point of time, most existing studies on the interactions between ICT use and mobility behaviour have been performed from a cross-sectional perspective, by which immediate interactions are examined. By contrast, some research, fuelled by the availability of panel data, has taken a longitudinal approach to investigating

evolutions in such interactions over time. Generally, this longitudinal analysis is based on the fact that there is increasing advancement and adoption of ICT for daily use, which may lead to dynamic effects on activity-travel behaviour. With the inclusion of a temporal perspective in studies, the long-term impact of ICT use, which may potentially reshape mobility patterns by more than simply inducing immediate behavioural changes, can also be examined. In addition, there may also be the necessity to consider the effects of past ICT experience on individuals' current behaviour according to behavioural theories. The theoretical underpinnings for the reliance of behaviour on past history have been conceptualised as hysteresis in behaviour (Georgescu-Roegen, 1971), which implies that current preferences and patterns are relative to the past history of behavioural choices (Elster, 1976).

Among the first to examine the dynamic effects of ICT adoption on travel behaviour were Hamer et al. (1991), who conducted an experimental panel study to monitor the changes in teleworkers' travel behaviour over five waves of data collection performed in approximately 3-monthly intervals between 1990 and 1991. Their study revealed that both the total travel by the teleworkers and peak hour car traffic were significantly reduced due to the adoption of teleworking. Mokhtarian and Meenakshisundaram (1999) applied a SEM approach to model the complex interactions between the amounts of travel and different forms of communication, including personal meeting, transfer of an information object, phone, fax, and email, over the period between 1994 and 1995. However, they found no significant relationship between the number of trips and the use of ICT-based communication. More recently, based on the Puget Sound Transportation Panel (PSTP)

data, Kim and Goulias (2004) modelled the relationships among time allocated to daily activities and travel, modal split, and changes in ICT ownership and availability between the years 1997 and 2000. They concluded that the effects of changes in ICT use depend on the location of the technology used (home or workplace). For example, new computer users at work tend to spend more time on subsistence activities and less time on leisure, while new computer users at home generally spend more time on all activities and tend to use public transportation more often. In the context of millennial studies, Thulin and Vilhelmson (2006) used the Swedish National Communication Survey data (1997–2001) to explore the impacts of young people's changing use of ICT on their in-home and out-of-home activity participation. The results revealed that increased computer use has no significant impact on young people's out-of-home activity engagement, but substantially displaces other in-home activities. Nobis and Lenz (2009) investigated the relationship between mobile phone use and mobility by using the panel data from Germany for the years 2004 and 2007. Their results rejected the assumption of substitution effects of ICT use, and indicated complementarity effects instead.

Apart from longitudinal or panel data, repeated cross-sectional (RCS) data can also enable the investigation of changes in effects and behaviour over time. Different to longitudinal survey data, where the same information is collected for the same individuals sampled over time, RCS data, adding temporal dynamics to cross-sectional data, repeatedly record the same (or similar) information for different samples of individuals each time (UKDS, 2015). Instead of measuring the changes at an individual level, therefore, studies based on analysis of RCS data tend to give estimates of change at a population or aggregate level

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(ibid.). Many findings of transport studies have been derived from analysing RCS data. For instance, Habib et al. (2012) explored the structural changes in commuting mode choices over ten years by using a large and repeated cross-sectional travel survey data set collected in the Greater Toronto and Hamilton Area in 1996, 2001 and 2006. They found that the major changes in choice preference structures occurred between 1996 and 2001 and stabilised between 2001 and 2006. By analysing the repeated cross-sections of the American Time Use Survey from 2003 to 2013, Garikapati et al. (2016) investigated the effect of aging on the activity and travel trends of millennials falling into different age groups. Their results showed that the older millennials (born 1979-1985) were aging to be increasingly similar to their prior generation counterparts in terms of activity-travel time use patterns, whilst the trends for the younger millennials born 1988-1994 were unclear. As for investigations of the dynamic relationship between ICT use and travel behaviour over time, Wilson et al. (2007) examined the changes in home ICT use and out-of-home activities for shopping and banking by comparing results from two independent but similar household surveys in 1995 and 2003. They found that both the frequencies of performing out-of-home and at-home shopping significantly increased in 2003, while the frequency of banking in either way did not change significantly compared to 1995. Pawlak (2014) made use of five cross-sectional datasets from the UK's Opinions and Lifestyles Survey (2005-2010) to get insights into how the ICT and travel behaviour interactions evolved over time. His findings suggested that the dynamic effects of Internet use on activity-travel behaviour varied according to different population segments characterised by their early or later adoption of the Internet.

2.3.3 Summary of empirical studies review

In summary, a large body of literature has suggested the diverse roles that ICT play in physical mobility from different research dimensions and perspectives. Such diversity is generally characterised by four types of ICT-travel interactions, i.e. substitution, complementarity, modification, and neutrality. These interactions have been well demonstrated by existing studies which have predominantly focused on the immediate or first-order effects of ICT use on mobility, though the interaction of substitution was overestimated in early studies. Since individuals' mobility behaviour is intrinsically and extrinsically characterised by various factors, such as socio-demographics, built environment and urban forms, intra-household interactions, attitudes and preferences, and generation, these factors may also shape their ICT-travel interactions. This has been sensed by several studies that have revealed differences in those interactions according to other factors, such as gender (Ren & Kwan, 2009) and residential location (Hong & Thakuriah, 2016). Hence, there may be a need to consider the role played by these additional factors in the ICT-travel relationships. The diversity of interactions could be further enriched if the indirect or higher-order effects of ICT on travel behaviour are better explored. Such a shift in research focus seems to be necessary in this information age, where increasing applications of ICT are causing more far-reaching impacts on people's daily lives as well as on their mobility patterns. Moreover, the rapid evolution of ICT over time calls for longitudinal analyses which investigate the long-term or dynamic interactions between ICT use and travel behaviour, and potentially increase the diversity in findings as well. Due to the deficiency of data sources, research taking the longitudinal point of view currently

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remains limited.

2.4 Summary of Chapter

The aim of this chapter was to provide theoretical, political and empirical background to the current research, summarise existing discourses and findings as well as highlight the potential for further exploration. In doing so, well-accepted theories and concepts for explaining sustainable development, the millennial generation, and travel and digital behaviour were firstly introduced to establish a solid theoretical foundation for the subsequent development of research methods and modelling strategies. Following that, the existing policy landscape of transport planning and ICT promotion was discussed, which demonstrates the increasingly important role ICT play in transport policy making for realising sustainable mobility, especially in the information age, where increasing digital inclusion is expected. Finally, and very importantly, empirical studies on travel behaviour determinants and on the ICT-travel interactions were systematically reviewed, with the proposal of three dimensions to characterise existing ICT-travel studies. Three limitations facing those studies were then identified. First, since factors like socio-demographics, spatial characteristics, and intra-household interactions significantly shape individuals' travel behaviour, they may also characterise the ICT-travel interactions. Second, research focus is still predominantly placed on the direct or first-order interactions; therefore, the indirect or higher-order interactions need to be afforded greater attention in order to gain deeper insights into this issue. Third, explorations of the long-term or dynamic interactions

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from a longitudinal perspective are insufficient. These underexplored areas will be targeted

by this research.

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Chapter 3 Data Sources and Research Methodology

This chapter endeavours to illustrate the overall research strategies adopted to integrate multiple components of the research process performed in this thesis in a consistent way, laying data and methodological foundations for subsequent quantitative analysis. In so doing, the data sources chosen for the planned analysis are introduced in Section 3.1, with discussion of issues related to background information, survey design, dataset structure, and data source employment strategy. The analytical methods and modelling techniques adopted in this research are then elaborated in Section 3.2, as well as the theoretical grounds for the modelling. Finally, this section ends with a concluding summary (Section 3.3).

3.1 Data Sources

The sources of data for this research are derived from second-hand household surveys and travel diaries at national or sub-national levels. Since both cross-sectional and longitudinal analyses are needed to answer the research questions proposed in the beginning, selected data sources must accommodate the data features (e.g. repeated recording, temporality) required by relevant quantitative analysis and modelling. These data sources must also meet other requirements in terms of, for example, sample size, the width, depth and aggregation level of the measured characteristics available. The Scottish Household Survey

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(SHS) and the Integrated Multimedia City Data (iMCD) Survey were selected as the data sources for the (repeated) cross-sectional analyses examining the varying effects of ICT use on human mobility and their changes over time. These data sources were major cross-sectional household surveys and a travel diary and are conducted annually in Scotland, The longitudinal (panel) analysis performed in this research to explore the effects of both current and past ICT usage on travel behaviour was made possible by using the Understanding Society (The UK Household Longitudinal Study) survey and its predecessor, the British Household Panel Survey (BHPS). These data sources and relevant datasets used in different analyses are introduced below.

3.1.1 Scottish Household Survey (SHS)

The Scottish Household Survey (SHS), started in 1999, is a continuous survey based on a sample of the general population in private residences across Scotland. It is sponsored by the Scottish Executive and undertaken by a consortium of research organisations, including Ipsos MORI and TNS Social. The aim of the survey is to provide accurate and up-to-date information about the compositions, characteristics, attitudes and behaviour of Scottish households and individuals, both nationally and at a more local level (Hope, 2007). The survey covers diverse topics, such as accommodation, finance, education, health, and travel, to facilitate the links between different policy areas for further analysis. Particular focus is placed on information to inform policy on transport, communities, and local government (ibid.). As for the sample of the SHS, it is designed to be nationally

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representative each quarter and to provide a representative sample for larger local authorities each year. Besides, the sample is also structured to collect data for each local authority over a two-year period until 2010, which is realised by disproportionately sampling in each local authority to achieve a target of at least 550 interviews over two years. For this research, a two-year sampling wave, namely, the 2005/2006 SHS, are used, with a total of 30,013 household interviews. The primary reason for such a selection is that the 2005/06 database is the last data version of the SHS containing the key information for the (repeated) cross-sectional analyses of this research, i.e. time spent on the Internet. Since 2007, the Survey stopped collecting such information.

In terms of survey methodology, the SHS uses questionnaires as the main survey instrument to collect data, and applies the techniques of Computer Assisted Personal Interviewing (CAPI) to retrieve information from the respondents during the face-to-face interviews. The survey questionnaire is in two parts. The household reference person, who is the Highest Income Householder (HIH) or his/her spouse/partner, completes the first part of the questionnaire, which deals with topics related to the overall conditions of the household, such as household composition, total income, housing and tenure, health, vehicles available to the household, and access to the Internet. Once the composition of the household has been established, one of the adults in the household is randomly selected to complete the second part of the interview dealing with individual issues regarding, for example, socio-demographics, personal income, neighbourhood problems, travel, use of public transport and the Internet. For the households with a single adult, the same person would complete both parts. Notably, the adult interview was not achieved in every

household surveyed. In the 2005/06 SHS, 28,261 (91% of total households) random adults were interviewed.

The essential aspect of the second part of the SHS, which has most relevance to this research, is the travel diary. The SHS Travel Diary asks the random adult of each household to provide detailed information on the personal travel s/he made for private purposes or for work or education on the day prior to the interview. The main reason for the journeys recorded should be for the traveller himself or herself to reach the destinations, which means that journeys made in the course of work by people who are employed (e.g. taxi drivers) are not covered in the travel diary. In general, the diary comprises personal trips made for work-related, domestic, social or recreational purposes, in addition to trips for taking or accompanying someone else (Scottish Government, 2007). As the basic unit of travel, a "journey" in the SHS Travel Diary is defined as a one-way course of travel having a single main purpose. Outward and return halves of a return journey are treated as two separate journeys. Moreover, a journey could consist of one or more stages, and a new stage emerges when there is a change in travel mode or when there is a change of vehicle requiring a separate ticket (ibid.). However, the single-stage journeys account for over 94% of the journeys recorded in the 2005/06 survey wave. As for the information on transport mode chosen for travel, when a journey involves more than one travel mode, only the main mode which is used for the longest (in distance) stage of the journey is recorded (Scottish Government, 2007). Furthermore, the origin and destination of each stage of each journey are also recorded by the interviewer and coded as a numeric variable in the dataset showing whether the origin/destination is "home", "work" or "other" places. The

interviewer also records the times at which stage of each journey started and ended. The length of each journey stage is the calculated straight-line distance as the crow flies based on the grid coordinates of the postcodes of the origin and destination of that particular journey stage (ibid.). An imputation process has been adopted to estimate the distance travelled when sufficient details of origin and/or destination are unavailable. The data for the SHS Travel Diary are supplied in two files, namely, a "Journey" file containing one record per journey (for multi-stage journeys, details of the origin of the first stage and the destination of the last stage are recorded), and a "Stage" file, containing one record for each stage of each journey. Considering the overwhelming dominance of single-stage journeys in survey records, the "Journey" data file was chosen for this research. By using the unique household identifier called "UNIQID", the travel diary data can be linked to the "main" SHS dataset recording other individual and household information.

For this research, the 2005/2006 SHS data (both the main data and travel diary data) are firstly used to examine the role of household working status in the relationship between use of the Internet and activity-travel behaviour. Together with the iMCD (Integrated Multimedia City Data) Survey data, which will be introduced in the following sub-section, they are then used to capture the changes in this relationship over time.

3.1.2 Integrated Multimedia City Data (iMCD) Survey

Funded by the UK Economic and Social Research Council (ESRC), the Integrated

Multimedia City Data (iMCD) Survey is also a household survey based on a sample of the general population in private residences across eight local authority areas of Glasgow and Clyde Valley (GCV) in Scotland, i.e. Glasgow City Council, North Lanarkshire, South Lanarkshire, Inverclyde, Renfrewshire, East Renfrewshire, East Dunbartonshire, and West Dunbartonshire. The survey fieldwork was also conducted by Ipsos MORI, with the adoption of Computer Aided Personal Interviewing (CAPI), and took place between April and November 2015. Similar to the SHS (Scottish Household Survey), the iMCD Survey was designed to draw an up-to-date picture of Scottish (Glasgow) households in terms of their values, attitudes, beliefs, and education, as well as the influences of these factors on behaviour and activity (Ipsos MORI, 2015). In terms of sample design, the smaller user subset of the Postcode Address File (PAF) (the most widely used sampling frame for general population surveys including the SHS) was adopted for selecting the sample for the iMCD Survey. The stratified random sampling approach was then employed to achieve the target household sample size (1,500), with the sample reflecting the balance of the population in the overall survey region. Moreover, in order to meet the target, the total number of households that would need to be contacted was calculated by using the historical data from the SHS. In fact, apart from survey implementation and sampling, the iMCD Survey also shared similar methodologies with the SHS in terms of survey structuring and weighting. The questionnaire of the iMCD Survey consists of three categories of questions. The household reference person, who was the highest income householder (HIH) or his/her spouse or partner, was firstly asked questions about the overall conditions of the household, such as composition, total income, and accommodation. All adults in the household were then asked the majority of the questions

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designed to collect personal information, including socio-demographics, behaviour, and attitudes. Notably, a variety of information on personal usage of ICT, including time use on ICT, was collected. To obtain information about their daily activity-travel patterns, the adults were also asked the Travel Diary component of the survey, which is based on and almost the same as the SHS Travel Diary., In addition, for reasons of space, a small number of questions related to cultural and civic activities were only asked to one adult randomly selected from the interviewed household. As for the survey weighting, the raw data collected by the Survey were calibrated with the National Records of Scotland's (NRS) mid-year population totals for 2015 and, for households, with the NRS household estimates, which is similar to how SHS datasets are formed. The overall household sample size achieved by the iMCD Survey is 1,505, and all adults in the sampled households were invited to participate in the Survey, leading to a total of 2,095 adults interviewed.

3.1.3 Understanding Society (the UK Household Longitudinal Study) and British Household Panel Survey (BHPS)

Started in 2009, Understanding Society, also known as the UK Household Longitudinal Study (UKHLS), is a major panel survey of the members of approximate 40,000 households across the UK. It is primarily sponsored by the Economic and Social Research Council (ESRC) with funding from multiple government departments, and periodically conducted by the Institute for Social and Economic Research (ISER) at the University of Essex. The British Household Panel Survey (BHPS), which ran for 18 waves from 1991 to

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2009, was also carried out by the ESRC and the ISER annually and subsumed into the

Understanding Society survey from Wave 19 in 2009. Thereafter, the BHPS sample

becomes a permanent part of Understanding Society. The objectives of the two

longitudinal surveys are the same, i.e., understanding the social and economic changes at

both household and individual levels, and facilitating the examination of the short- and

long-term effects of such changes, including policy interventions, on the general

well-being of the UK population (Taylor, 2010; Knies, 2014).

Both Understanding Society and the BHPS are annual surveys involving each adult

member (aged 16 years and over) of the nationally representative samples. The same

individuals are re-interviewed in each wave of the survey, approximately 12 months apart.

However, unlike the BHPS, which completes each wave annually, data collection for each

wave of the Understanding Society surveys takes place over a 24-month period. The

periods of waves overlap, and the individual respondents are interviewed around the same

time each year. For example, the first wave of data was collected between January 2009

and January 2011, the second wave between January 2010 and January 2012, and so forth.

If the individuals interviewed in either of the two surveys move out of their original

households, they are followed to their new addresses within the UK, and all adult members

of their new households are also interviewed. As for the sample structure, the initial sample

for Wave 1 of the BHPS consisted of 8,167 issued household addresses drawn from the

Postcode Address File, and all these sample members were known as Original Sample

Members (OSMs). The sample for the following waves encompasses all adults in all

households containing at least one member who was resident in a household interviewed in

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Wave 1, regardless of whether or not that individual was interviewed in Wave 1 (Taylor, 2010). Children in sample households are interviewed once they reach the age of 16, and there is also a special survey of household members aged 11-15 included in the BHPS from Wave 4 onwards (the Youth Questionnaire). The BHPS in Scotland and Wales was extended with the addition of two further samples in Wave 9 and in Wave 11, and a substantial new sample in Northern Ireland was added so as to increase the sample coverage of the entire UK. As for the Understanding Society survey, there are five sample components, including the General Population Sample (GPS), the Ethnic Minority Boost (EMB) sample, the General Population Comparison (GPC) sample, the UK Innovation Panel (IP) sample, and the former BHPS sample which was incorporated in Wave 2 of Understanding Society. Similar to the BHPS, young people aged 10-15 in households are asked to respond to a self-completion questionnaire from Wave 1 of the survey.

The two surveys also adopt similar methodology and instruments for collecting data. Four questionnaires shape the structure of the two surveys: a) a household questionnaire, which includes household composition data and lists information about all household members regarding, for example, gender, date of birth, marital and employment status, together with questions about housing, household income, car availability, consumer durables, Internet access, and so on; b) an individual questionnaire, completed by every adult member of the household, covering diverse topics such as socio-demographic status, neighbourhood, residential mobility, health and care, environmental and transport behaviour; c) a self-completion questionnaire, which follows the individual questionnaire and includes subjective or attitudinal questions about, for instance, feelings of depression and

well-being, neighbourhood participation and belonging, life satisfaction, and environmental attitudes and beliefs; and d) a youth questionnaire, which is completed by minors in the household (aged 11-15 years in the BHPS, aged 10-15 years in Understanding Society) and includes questions on family support, computer and technology use, feelings about areas of life, health behaviour, smoking and drinking, aspirations, and so on. Since the BHPS sample was incorporated into Understanding Society in 2009, each of the BHPS sample members is now issued with a unique identifier within the Understanding Society datasets, which allows users to match BHPS data to data from Understanding Society Wave 2 onwards.

3.1.4 Strategic roles of data sources in research design

According to their different forms, focus, and temporal horizons, each data source introduced above is individually utilised to address certain research objectives and relevant questions. As previously suggested, the 2005/2006 SHS data are used to perform cross-sectional analysis concerning the varying effects of Internet use on activity-travel behaviour according to household working status - a requirement of Objective A (see Chapter 1). Meanwhile, the iMCD Survey and the 2005/06 SHS data are used together for the repeated cross-sectional analysis aimed at examining the temporal changes in the relationship between Internet use and activity-travel behaviour, with particular attention paid to millennials (Objective B). Lastly, to address Objective C, the 2004 BHPS data and the 2012/13 Understanding Society (Wave 4) data are combined for the longitudinal

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analysis exploring the long-term effects of past ICT experiences on travel behaviour as well as attitudes towards the environment.

3.2 Analytical Methods and Modelling Techniques

Based on those large-scale survey data, two model paradigms, i.e. the two-part model (2PM) and the structural equation model (SEM), are primarily employed in this research to investigate the complex relationships between ICT use and mobility behaviour. In Chapter 5, the 2PM is applied together with the difference-in-differences (DD) method to capture the temporal changes in such relationships. The adoption and requirements of the these models are mainly determined by the research objective and the questions to be addressed, the data features, and the variables included, which will be discussed in the analytical chapters (i.e. Chapters 4, 5 and 6). This section expounds the strengths, structures, and mathematical settings of the two model paradigms (2PM and SEM) and the DD estimation, as well as the theories underpinning the modelling practices.

3.2.1 Two-part model (2PM)

A data issue confronting the analyses conducted in Chapter 4 and 5 is that there is a large proportion of zero values included in the activity-travel variables, i.e. the dependent variables. In this case, as the assumption of normal distribution cannot be satisfied, the

traditional OLS (ordinary least squares) estimation would not be efficient any more. When seeking proper models to accommodate such data features, there is one key fact that needs to be recognised, namely, that both the zero and the non-zero observations suggest individuals' choices in terms of whether or not they undertake the activities/trips on a given day. Modelling the effects of ICT use on activity-travel behaviour is based on the cases in which individuals made the choice to go out for specific activity purposes (i.e. non-zero observations), but the zero observations cannot simply be ignored as they represent the opposite choice. Accordingly, a process of sample identification or selection in terms of travel choice making needs to be embodied within potential models. The Heckman two-stage model and the two-part model (2PM), which have commonly been applied to address this selection issue are the most qualified candidates.

3.2.1.1 Choosing the 2PM

The relative merits and demerits of the Heckman model and the 2PM have been the subjects of vigorous debates in the literature (e.g. Duan et al., 1984; Hay & Olsen, 1984; Lueng & Yu, 1996; Dow & Norton, 2003), with most of the arguments focusing on their underlying assumptions and numerical properties. One key assumption concerns the treatment of the zero observations as actual outcomes or potential outcomes. The actual outcome is a fully-observed variable, whereby the zero values in the data are treated as "true" zeros rather than as missing values when modelling. In this case, these actual zero values are referred to as "corner solutions", as individuals cannot have negative activity-travel time use. If many observations have zero values, then the econometric

challenge is to model these corner solutions. The potential outcome, by contrast, is a latent variable which is only partially observed. More specifically, the non-zero values are treated as the true observations of the potential outcome, but the zero values indicate observations for which the potential outcome is missing or latent. Since such a partially observed latent variable treats zeros in the data as censored, inclusion of the inverse Mills ratio, which is usually calculated to take account of the selection bias in the Heckman model, is needed in the second stage regression (Vance & Hedel, 2007). As suggested by Dow and Norton (2003), for model choice, 'it is critical to clearly specify whether the outcome of interest is the actual or the potential' (Dow & Norton, 2003), because the Heckman model and the 2PM have different strengths and weaknesses when employed to deal with actual or potential outcomes. The Heckman selection model was originally designed to address selection bias for analysing potential outcomes, hence, its estimator incorporates features (e.g. the inverse Mills ratio) which make it often perform worse than the 2PM when modelling actual outcomes (Duan et al., 1984). In contrast, the 2PM, which generates actual outcomes without considering selection problems, would suffer from selection bias if those with missing (zero) values systematically differ from those with observed (non-zero) values of a potential outcome (ibid.). In this research context, the potential outcome addresses the time an individual would spend on activity participation and trip making, irrespective of actual undertaking, whereas the actual outcome addresses the observed time spent by those who have chosen to undertake the activities and trips. As the latter interpretation provides tighter conceptual fit with the aim of this study, which is to examine the effects of ICT use on actual activity-travel time use, the 2PM is seen as a more appropriate modelling specification for application. In addition, another reason for

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dropping the option of the Heckman model is because of the high-standard errors on its coefficient estimates and parameter instability, which are expected when there exists a high degree of collinearity between the explanatory variables and the inverse Mills ratio — an additional regressor included in the Heckman model for controlling potential selectivity bias (Vance & Hedel, 2007).

3.2.1.2 Structuring the 2PM

Instead of directly making an estimation of the whole observation, the two-part model (2PM) involves a two-stage modelling procedure that orders observations into two regimes. The first part estimates the probability of occurrence in a certain activity, which in this research situation refers to the probability of undertaking out-of-home activities or tips. The second part of the model estimates the level of that activity conditional on its occurrence (Heres-Del-Valle & Niemeier, 2011). The whole 2PM then incorporates the probability of observing the dependent variable y > 0 to yield the following expected value of y for any observations:

$$E\ [y|X] = Prob\ [y > 0|X]\ \times E\ [y|X, y > 0] \tag{3-1}$$

where y is the dependent variable, measured here as the activity-travel time use, and X is a vector of observed explanatory variables of interest, such as socio-demographics and ICT use.

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The first part of 2PM, which is viewed as a selector equation, predicts the probability of choosing to undertake activities/trips for whole observations, usually specified as a probit model:

$$Prob \ [y > 0|X] = \Phi \ (\tau^T X) \tag{3-2}$$

where Φ denotes the standard normal cumulative distribution function and τ^T is a vector of associated coefficient estimates;

or a logit model:

$$Prob \ [y > 0|X] = \frac{\exp(\tau^T X)}{1 + \exp(\tau^T X)} \tag{3-3}$$

As the probit and logit models generate very similar results regardless of their different assumptions about distribution of errors (i.e. normal distribution is assumed in the probit model, standard logistic distribution is assumed in the logit model), they can be alternatively chosen to specify the selector equation. In this research, the probit model (Eq. 3-2) is selected. Notably, the estimated coefficient vector τ^T in Eq. (3-2) does not directly quantify the effects of explanatory variables on the probability of occurrence ($y > 0$). Instead, the marginal effect is usually adopted to measure the effect of a unit change in the variable of interest x_k on the probability *Prob (y > 0).* As this marginal effect is derived from the partial derivative of the event probability with respect to the predictor of interest (x_k), it can be computed as:

$$\frac{\partial Pr[y>0|X]}{\partial x_k} = \frac{\partial \Phi(\tau^T X)}{\partial x_k} = \tau_k \phi(\tau^T X) \tag{3-4}$$

where τ_k is the estimated coefficient in terms of x_k, and ϕ denotes the standard normal density, namely, the derivative of Φ above.

After estimating τ^T in Eq. (3-2) using the maximum likelihood method, the second stage of modelling, which is commonly referred to as an "outcome equation", involves estimating a regression of activity-travel time use conditional on $y > 0$ (i.e. non-zero observations). The outcome equation is usually specified in two ways: an OLS (ordinary least squares) regression model with a transformed dependent variable, or a generalised linear model (GLM). If choosing the OLS model, the dependent variable y is commonly log transformed to ensure its positivity, as the log transformation can "pull in" the upper tail of the distribution (Buntin & Zaslavsky, 2004). Hence, the outcome equation can be expressed as:

$$E\ [ln(y)|y>0,\ X] = \beta^T X \tag{3-5}$$

After modelling, predictions need to be retransformed back to the original scale to draw conclusions about the original variables, which means the Eq. (3-5) is then retransformed as follows:

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$$E\ [y|y > 0,\ X] = exp\ (\beta^{T}X + 0.5\sigma^{2}) \tag{3-6}$$

where β^{T} represents another vector of coefficient estimates derived from the OLS model.

However, if the log-scale error terms/residuals from Eq. (3-5) are not

homoskedastic-normally distributed, which implies the presence of heteroskedasticity (i.e.

error variance dependent on X), the retransformation results derived from Eq. (3-6) could

be biased (Mullahy, 1998; Manning & Mullahy, 2001; Buntin & Zaslavsky, 2004). By

contrast, if the outcome equation is specified as a GLM, which, in practice, is usually

chosen with a log link function (Mullahy, 1998), it can directly provide the estimates for

the original data without any retransformation as follows:

$$E[y|y > 0, X] = exp(\delta^{T}X) \tag{3-7}$$

where δ^{T} is again the coefficient vector estimated by the GLM. Nevertheless, as a natural

consequence of its weaker model assumptions, the GLM may provide less precise

estimates than the OLS model does. Besides, since the log-link relationship is commonly

chosen to form the GLM, if the log scale residuals are heavy-tailed with high kurtosis, the

GLM estimates could be quite imprecise (Manning & Mullahy, 2001). Accordingly, model

selection involves important tradeoffs between the two estimators in terms of estimate

precision and bias. In order to ease the process of model selection, Manning and Mullahy

(2001) empirically suggested a strategy, which is experiment-and-check based, to help

researchers make their choices. According to their strategy, the OLS model with

log-transformation is initially experimented as the potential model, since it is usually

preferred due to its strong and rigorous model assumptions. Both the Breusch-Pagan test (Breusch & Pagan, 1979) and the White test (White, 1980) are then applied to check the log-scale residuals from the transformed model in terms of homoskedasticity. If heteroskedasticity is not detected in either test, the log-transformed OLS model can be adopted to specify the second stage of the 2PM; otherwise, the GLM model with a log link function is preferred.

By combining the selector equation of the first stage (Eq. 3-2) and the outcome equation of the second stage (Eq. 3-6 or Eq. 3-7), the expected value of y for the full sample (including both the zero and non-zero observations) can be expressed as:

$$E [y|X] = \Phi (\tau^T X) \, exp \, (\beta^T X + 0.5\sigma^2) \tag{3-8}$$

or, for the GLM case:

$$E [y|X] = \Phi (\tau^T X) \, exp(\delta^T X) \tag{3-9}$$

Similar to the result explanation for the probit model, the regression coefficient estimates cannot directly measure the effects of explanatory variable X on the dependent variable y, due to the nonlinearity of the model. Hence, marginal effect, which measures the effect of a unit change in X on y, is computed by taking the partial derivative of $E [y|X]$ with respect to the predictor of interest x_k:

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$$\frac{\partial E[y]}{\partial x_k} = \beta_k \Phi(\tau^T X) exp(\beta^T X + 0.5\sigma^2) + \tau_k \phi(\tau^T X) exp(\beta^T X + 0.5\sigma^2) \qquad (3\text{-}10)$$

or, for the GLM case:

$$\frac{\partial E[y]}{\partial x_k} = \delta_k \Phi(\tau^T X) exp(\delta^T X) + \tau_k \phi(\tau^T X) exp(\delta^T X) \qquad (3\text{-}11)$$

where ϕ is the standard normal density (i.e. the derivative of Φ).
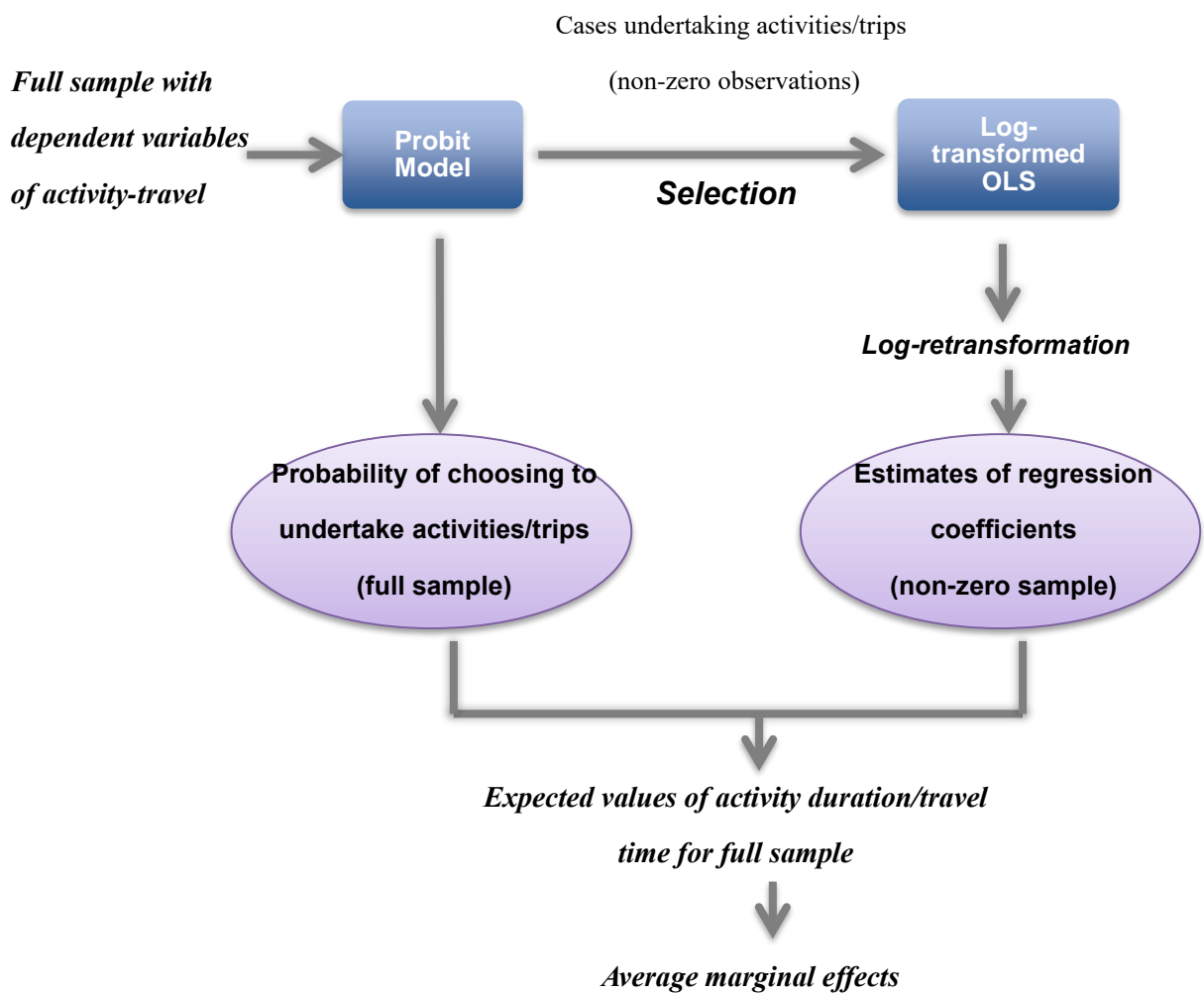
Fig. 3-1 Modelling process of the 2PM

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In the studies performed in Chapters 4 and 5, the long-transformed OLS model was chosen to specify the second stage of the 2PM, as the experiment-and-check approach revealed that there is no heteroskedasticity issue in terms of the log-scale residuals from the transformed model. All the processes of the modelling strategies, elaborated above, are summarised and illustrated in Fig. 3-1.

3.2.2 Difference-in-differences estimation and pooling cross sections

The difference-in-differences (DD) estimation is a widely used technique to evaluate the effects of a specific intervention or treatment on relevant outcome variables (Abadie, 2005; Bertrand et al., 2004). In doing so, it compares the differences in outcomes before and after the treatment for the group affected by the treatment with the same difference for the unaffected group (Bertrand et al., 2004). Therefore, it is normally required to collect data for a "treatment group" and a "control group" in two or more different time periods. The DD settings fit into the research context of Chapter 5, where an attempt is made to seek the difference over time in the average difference of activity-travel outcomes with and without the effect of ICT use.

Before applying the DD estimation for the repeated cross-sectional study, the samples from two cross-sectional survey waves, referring to the 2005/06 SHS (Glasgow and Clyde Valley sample) and the 2015 iMCD Survey in Chapter 5, are firstly pooled. As indicated by Wooldridge (2013), using pooled cross sections data increases the sample size, which will

generate more precise estimators and test statistics with more power. More importantly, it raises only minor statistical complications when modelling the temporal changes occurring in the same population (Wooldridge, 2013). To reflect the fact that the population may have different distributions at different points of time, the intercept term of the assumed relationship is normally allowed to differ across periods. It is accomplished by including indicators or dummy variables for all but the earliest year in the pooled sample, as the earliest year is commonly chosen as the reference. Apart from serving as standalone variables to reflect the changes in constant term, which indicate the effects of time or wave on the outcomes, such dummy variables can also be used to interact with key explanatory variables to examine the changes in the effect of that variable over a certain time or survey period (ibid.). The coefficient of the interaction term is the difference-in-differences (DD) estimator measuring such temporal changes. In extreme cases, all the predictors in the regression model can interact with the year/wave indicators. After running the regression in this form, a single set of estimates will be gained with each year/wave having its own regression coefficients. This process is quite similar to the notion of estimating the equation separately for each year, except for assuming homoskedasticity throughout the independently pooled cross sections. For the study in Chapter 5, a simple regression model of the relationship between the independent variable y (i.e. activity-travel time use), and a set of socio-demographic predictors X_{SD} and ICT-usage predictors X_{IU} can be initially formulated as Eq. 3-12 without consideration of temporal change:

$$y = \beta_0 + \beta_{SD}^T X_{SD} + \beta_{IU}^T X_{IU} + u \tag{3-12}$$

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where β_{SD}^T and β_{IU}^T is the vector of coefficient estimates for X_{SD} and X_{IU}, respectively, while β_0 is the constant term. After pooling the two cross sections, the 2005/06 SHS (*W1)* and the 2015 iMCD (*W2)*, a dummy variable δ_{W2} is then created to indicate whether or not a specific respondent belongs to *W2*. In this case, according to the DD settings and particularly considering the temporal dynamics in the relationship between Internet use and travel behaviour, the regression model is formulated as Eq. 3-13 below:

$$y = \beta_0 + \boldsymbol{\beta_{0W2}\delta_{W2}} + \beta_{SD}^T X_{SD} + \beta_{IU}^T X_{IU} + \boldsymbol{\beta_{IUW2}^T\delta_{W2}X_{IU}} + u \qquad (3\text{-}13)$$

The additional coefficient estimate β_{0W2} represents the change in constant item observed in *W2* (2015) as compared to *W1* (2005/06), based on the assumption of common error for the pooled datasets. The coefficient vector β_{IUW2}^T is the DD estimator which measures the changes in the effects of ICT use on activity-travel behaviour, i.e. the outcome variable in the model, over the two survey periods. In this situation, β_{IU}^T captures the differences in activity-travel outcomes between the ICT users (treatment group) and the non-users (control group) in the referenced year (*W1*). In order to get an overall trend of changes in the ICT-travel relationship over time, Eq. 3-12 is firstly estimated for each wave with application of the two-part model, which is somewhat equivalent to running the regression with all regressors interacting with the wave indicator. Comparison is made based on the two individual sets of estimates. Pooling cross sections is subsequently implemented for estimating Eq. 3-13, capturing the exact difference-in-differences.

3.2.3 Structural equation model (SEM)

As a modelling technique excelling in investigating complicated causal relationships among multiple factors, the structural equation modelling (SEM) can deal with a large number of endogenous and exogenous variables, as well as latent variables linearly specified by multiply observed ones. A typical SEM with latent variables usually consists of two components: a measurement model and a structural model. The measurement model specifies how latent variables are explained by the observed variables, while the structural model specifies the relationships among latent variables and captures the regression effects of exogenous (independent) variables on endogenous (dependent) variables, as well as the effects of endogenous variables on each other. The measurement model can be further classified into the measurement model for the endogenous variables (y) and the measurement model for the exogenous variables (x). The matrix formulation of a typical SEM with latent variables can be explained as follows:

Measurement model for endogenous variables: $\qquad \boldsymbol{y} = \boldsymbol{\Lambda_y \eta} + \boldsymbol{\varepsilon}$ $\qquad$ (3-14)

Measurement model for exogenous variables: $\qquad \boldsymbol{x} = \boldsymbol{\Lambda_x \xi} + \boldsymbol{\delta}$ $\qquad$ (3-15)

Structural model: $\qquad \boldsymbol{\eta} = \boldsymbol{B\eta} + \boldsymbol{\Gamma\xi} + \boldsymbol{\zeta}$ $\qquad$ (3-16)

where $\boldsymbol{y}$ is $p \times 1$ vector of observed endogenous variables;

$\qquad \boldsymbol{x}$ is $q \times 1$ vector of observed exogenous variables;

$\qquad \boldsymbol{\eta}$ is $m \times 1$ vector of latent endogenous variables;

$\qquad \boldsymbol{\xi}$ is $n \times 1$ vector of latent exogenous variables;

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$\boldsymbol{\varepsilon}$ is p×1 vector of measurement errors in $\boldsymbol{y}$;

$\boldsymbol{\delta}$ is $q \times 1$ vector of measurement errors in $\boldsymbol{x}$;

$\boldsymbol{\Lambda_y}$ is $p \times m$ matrix of coefficients of the regression of $\boldsymbol{y}$ on $\boldsymbol{\eta}$;

$\boldsymbol{\Lambda_x}$ is $q \times n$ matrix of coefficients of the regression of $\boldsymbol{x}$ on $\boldsymbol{\xi}$;

$\boldsymbol{B}$ is $m \times m$ matrix of coefficients of $\boldsymbol{\eta}$ in the structural relationships;

$\boldsymbol{\Gamma}$ is $m \times n$ matrix of coefficients of $\boldsymbol{\xi}$ in the structural relationships;

$\boldsymbol{\zeta}$ is $m \times 1$ vector of equation errors in the structural relationships.

In practice, this full model is seldom applied due to its complexity and operational difficulties, and one or both of the measurement models are usually dropped (Kaplan, 2000). An SEM only with observed variables is analogous to a path analysis, and a measurement alone can be regarded as a confirmatory factor analysis. In this research, only one latent endogenous variable is constructed, i.e. positive attitude towards environment (see Chapter 6), and there is no specified measurement model for exogenous variables.

In SEM, the effects of one variable on another are specified as three types: direct, indirect, and total effects. The direct effects, which are estimated as $\boldsymbol{B}$ and $\boldsymbol{\Gamma}$ in Eq. 3-16 above, are the direct links 'between a productive variable and the variable that is the target of the effect' (Golob, 2003), and are not intercepted by any intermediaries. In contrast, the indirect effects include all the effects along the links between the two variables that involve intervening variables. Therefore, the total effect is the sum of direct effects and indirect effects. Accordingly, interpreting a model with the direct effects only may result in misleading conclusions, and it is the total effects that should be used in interpretation. Such

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a technique is most needed in the study in Chapter 6, as it seeks to explore the mediating

effects of environmental attitudes on the relationships between Internet use and behaviour.

The SEM system is generally estimated by using covariance analysis, which works by

'finding model parameters such that the variances and covariances implied by model

system are as close as possible to the observed variances and covariances of the sample'

(Golob, 2003). The most commonly used SEM estimation methods include

maximum-likelihood (ML), generalised least squares (GLS), weighted least squares (WLS),

asymptotically distribution-free weighted least squares (ADF or ADF-WLS), and, more

recently, weighted least squares means-adjusted (WLSM) and weighted least squares

means-and-variance-adjusted (WLSMV) estimation (Muthén & Muthén, 2004). Selection

of an appropriate SEM estimation method needs a comprehensive consideration of the

assumptions underpinning each estimator, the scale properties of the variables, sample size,

and the complexity of the SEM (Kaplan, 2000). For instance, although the most preferred

method is the ML estimator, whose basic assumption is the multivariate normal

distribution of all continuous endogenous variables in the model (Kline, 2005), this

assumption is not always fulfilled in reality, and violations from normality would lead to

estimation biases and model non-convergence (Bollen, 1989; Finch et al., 1997; Hoogland

& Boomsma, 1998). By contrast, the WLS estimator makes no assumption of normality

(Golob, 2003), but due to its heavy reliance on asymptotic assumptions and complicated

matrix computation (Finney & DiStefano, 2006), it normally requires very large sample

sizes, which are suggested to be 1,000 to 5,000 (West et al., 1995; Yuan & Bentler, 1998),

for results to converge to stable estimates. However, by decreasing the computational

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intensity embedded in the traditional WLS estimation, the robust WLS estimators (i.e. WLSM and WLSMV) can avoid the necessity of a large sample size (Finney & DiStefano, 2006), which are suitable for the analysis of Chapter 6, where all the observed endogenous variables are ordered categorical variables with non-normal distribution, and the sample size is moderate.

In terms of model evaluation, many criteria have been developed to assess the overall goodness-of-fit of an SEM, and most of them are based on the chi-square statistic (χ^2) given by 'the product of the optimised fitting function and the sample size' (Golob, 2003). Nevertheless, which measure should be used is still a difficult and controversial issue (Arbuckle & Wothke, 1999). The measures and criteria that are commonly used include:

- **Chi-square ($\chi 2$):** traditional measure for evaluating overall model fit by assessing the 'magnitude of discrepancy between the sample and fitted covariance matrices' (Hu & Bentler, 1999). A smaller value generally implies a better model, and a good model fit would provide an insignificant result at a 0.05 threshold (p-value). However, this measure is problematic for large sample sizes and deviations from multivariate normality assumptions. The relative/normed chi-square (χ^2/d.f.) is developed to minimize the impact of sample size, with a value of less than 5 implying an acceptable level (Wheaton et al., 1977).

- **Normed Fit Index (NFI):** assesses the model by comparing the χ^2 value of the model with the χ^2 of the null model. The null model is treated as the worst-case scenario in

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which all measured variables are uncorrelated. In general, an NFI value greater than

0.90 indicates that the model fit is acceptable (Bentler & Bonnet, 1980).

• **Tucker–Lewis index (TLI):** also known as the non-normed fit index (NNFI), analyses

the discrepancy between the chi-squared value of the hypothesised model and that of the

null model, with a penalty for adding parameters. Values over 0.90 or over 0.95 are

generally considered acceptable (Hu & Bentler, 1995).

• **Comparative fit index (CFI):** a revised form of the NFI which takes into account

sample size (Byrne, 1998), representing the ratio between the discrepancy of the target

model and the discrepancy of the independence model. Values closer to 1 generally

indicate an acceptable fit.

• **Root mean square error of approximation (RMSEA):** measures the population

discrepancy per degree of freedom to compensate for the effects of model complexity.

Values less than 0.05 indicate a good fit, and values as high as 0.08 represent a

reasonable fit (Browne & Cudeck, 1993). Usually, a close-fit test for null hypothesis

(H_0: RMSEA $\leq$ 0.05) is conducted together with the estimation of RMSEA value, and

the p-value is used to examine the alternative hypothesis (H_A: RMSEA $>$ 0.05). P $>$ 0.05

(insignificance) indicates a close fit, since the null hypothesis cannot be rejected.

• **Standardised/weighted root mean square residual (SRMR/WRMR):** square root of

(weighted) discrepancy between the residuals of the sample covariance matrix and the

hypothesised covariance model. Values less than 0.08 can be considered as a good fit (Hu & Bentler, 1999). For WRMR, which is normally reported for model evaluation with use of the robust WLS estimators, values less than 1.0 are generally acceptable (Yu, 2002).

3.2.4 Theoretical grounds of modelling

In this research, travel demand/behaviour modelling is employed to investigate individuals' travel behaviour under the effects of ICT adoption. Apart from the statistical theories and techniques introduced above, the modelling practices are rationalised and fuelled by a series of economic and behavioural theories which have been expatiated in Chapter 2. In general, all the travel modelling follows a conceptual framework, based on the traditional philosophy, from which the travel demand for most trip purposes is derived (e.g. Crane & Crepeau, 1998; Mokhtarian & Salomon, 2001). People travel normally not for the sole sake of travelling, but for the benefits derived at the destinations where activities take place. Hence, travellers are assumed to make logical and rational travel decisions in terms of choices related to travel purpose, frequency, timing, duration, destination, and transport mode to maximise their benefits and utility but subject to budget constraints, both in money and time. This assumption complies with the classical rational choice or utility maximisation theories that have traditionally been applied in travel modelling. In addition, the general principles of social-psychological behavioural theories (e.g. the theory of planned behaviour and the self-perception theory), which highlight the causal relationship

between attitude/perception and behaviour, are also embodied in this research when modelling people's travel choices and frequency.

There are two main approaches in travel demand/behaviour modelling: trip-based and activity-based modelling. The choice between them largely depends on the data source for analysis as well as on the research focus placed on trip making or on activity undertaking. As introduced in Chapter 2, the activity-based approach (ABA) attempts to explain travel as a derived demand for activity participation from a spatial or temporal perspective, which is suitable for modelling strategies based on the SHS data and the iMCD Survey data, since information on both trip making and activity performing in terms of purposes and time use is available from the travel diary datasets. The trip-based approach, which only examines the trip characteristics without considering the underlying activity demands, is adopted by the longitudinal analysis based on the BHPS and Understanding Society survey data, as only trip information (mode choice and trip frequency) is available and, therefore, modelled. As for the inclusion of variables in travel behaviour models developed in this research, variables measuring activity-travel behaviour and ICT adoption are the models' key dependent (or endogenous) and independent (or exogenous) variables, respectively, as this research generally focuses on the relationship between mobility behaviour and ICT use. In addition, socio-demographics, such as gender, age, number of kids/cars and income, are also considered as independent variables since they have been widely proven to have effects on activity-travel behaviour, and such effects need to be controlled in studies. Moreover, as suggested in Section 2.3.1, the built environment or residential location can also shape people's mobility patterns, meaning that the inclusion of such variables is

necessary. In the millennial study addressing Objective C, the tendency of delayed transitions into adulthood, such as living with parents beyond reaching adult age, is always seen as an important factor in understanding young people's behaviour. Hence, living with parents or not is also included as an explanatory variable when modelling millennials' mobility behaviour.

3.3 Summary of Methodology Chapter

This chapter elaborated the overall research strategy and methodological framework employed in this research. The sources of data are derived from four (sub-) national household surveys: the Scottish Household Survey (SHS), the Integrated Multimedia City Data (iMCD) Survey, Understanding Society (the UK Household Longitudinal Study), and its predecessor, the British Household Panel Survey (BHPS). According to their different forms, focuses and temporal horizons, each data source, as well as its combination with another one, is utilised strategically to address one of the three research objectives. Based on these survey data, two model paradigms, i.e. the two-part model (2PM) and the structure equation model (SEM), are adopted to investigate the diverse ICT-travel interactions which are the focus of this research. In addition, theoretical grounds are also illustrated for the subsequent modelling practices, in terms of underlying theoretical assumptions, choice of modelling approaches, and inclusion of variables in models.

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Chapter 4 Effects of Household Working Status on the Relationship Between Internet Use and Activity-Travel Behaviour

As reviewed in Chapter 2, several studies have empirically demonstrated that certain attributes, such as place of residence and gender, matter for the relationship between ICT use and activity-travel behaviour (Ren & Kwan, 2009; Hong & Thakuriah, 2016). Household working status could arguably be another such attribute which is worth considering when modelling the ICT-induced effects. Inspiration for this intuition is drawn from the previous research findings summarised in Chapter 2. First, work activities, which are comparatively fixed in time and space, to a large extent determine people's opportunities to undertake other non-work activities, thereby shaping their daily activity-travel patterns (Hägerstrand, 1970; Schwanen & Dijst, 2003). Second, the employment status of other members of households is also found to impact on individual mobility behaviour through the intra-household interactions, including time and activity allocations to household members (e.g. Scott & Kanaroglou, 2002; Vovsha et al., 2004; Srinivasan & Bhat, 2005). Third, some research has implied that workers tend to use ICT (e.g. teleshopping and e-banking) to replace their physical non-work activities and associated travel due to the strict time constraints imposed by their work (e.g. Farag, Dijst & Lanzendorf, 2003; Srinivasan & Athuru, 2004). These findings imply that household working status can potentially affect personal decisions regarding activity, especially

non-work activity participation and associated trip-making, at both the individual and household level; hence, the ICT-induced effects could vary among persons from households with different working status.

Based on the arguments and assumptions made above, this chapter investigates how the effects of ICT use on individuals' activity-travel behaviour differ according to their household working status. The chapter starts by identifying its research objective and questions (Section 4.1). Essential matters about the data, namely, the 2005/06 Scottish Household Survey (SHS) data, are then stated in Section 4.2, including data preprocessing, variable generation, and descriptive statistical analysis of variables. Thereafter, the results of the two-part model (2PM) and research findings are discussed in Section 4.3, which is followed by a concluding summary ending with policy implications (Section 4.4).

4.1 Objective and Research Questions

The two general purposes of this study, as stated in **Objective A** of this thesis, are to enrich the ICT-travel literature by suggesting the potential effects of household working status on the relationship between ICT use and activity-travel behaviour, and to inform planners and policy-makers of the necessity of getting more accurate and holistic travel demand predictions in the information age for specific individual and household types. With these aims in mind, this study examines how the amount of time spent on the Internet for personal purposes impacts on people's non-work or non-mandatory activity (i.e.

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maintenance and leisure activity) undertaking and related trip-making on weekdays, and how such impacts vary according to household working status. More specifically, three research questions, proposed to address **Objective A**, will be answered:

a) What are the effects of the amount of time spent on the Internet on individuals' time use for *maintenance activities* and associated travel?

b) What are the effects of the amount of time spent on the Internet on individuals' time use for *leisure activities* and associated travel?

c) Do these effects vary according to household working status? If so, to what extent do the effects vary according to household working status?

4.2 Data Preprocessing and Variable Generating

As introduced in Chapter 3, the 2005/06 Scottish Household Survey (SHS) database, which includes both main dataset and travel diary dataset, was used to perform this study. The database originally includes 30,013 household records and 28,261 adult cases. It reveals massive amounts of information about households (e.g. composition, total income, number of kids and vehicles) and individuals (e.g. age, gender, employment status, use of the Internet and travel) in Scotland. For this study, the key variables are derived from the information revealing individuals' travel behaviour and their usage of the Internet, as the

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research questions centre around the relationships between the two elements. Besides the key variables of interest, socio-demographic and residential location (built environment) variables are also considered, as their potential effects on travel behaviour need to be controlled in analysis. Moreover, as the assumption is made that the relationships may vary according to household working status, variables directly or indirectly reflecting such status for a household are also essential for consideration. Data processing for generating these four groups of variables is illustrated as follows.

4.2.1 Activity-travel behaviour (time use)

Information on individuals' travel behaviour and trip making is revealed by the SHS travel diary dataset, with detailed records of each journey made by the random adults on a given day. In the original dataset, although travel time is directly reflected as the variable of journey duration in minutes for each trip, information on activity participation is not readily available. Since both the start and end times of each journey are recorded in the dataset, in order to ascertain the activity time use, the duration of activity performing was calculated by subtracting the arrival time of the last trip from the departure time of the next trip for each random adult. As for activity purposes, the 21 activity types in the original dataset, recorded as the purposes for each journey, were then classified into three activity categories based on the practices used in previous studies to analyse activity-travel time-use (see Section 2.1.4.3), namely, *mandatory or subsistence activities* (including work, studying at school/college, and attending training schemes); *maintenance activities* (e.g.

shopping, banking, doctor visiting, picking-up/dropping-off children); and *leisure activities* (including friend visiting, sporting activities, day trips, entertainment activities, etc.). As a result, for each adult interviewed in the survey day, the time-use and purpose of each activity they performed became available. In addition, the total travel time for each adult was computed and then classified, based on the types of activities for which the adult travelled (i.e. time of travel for subsistence, maintenance and leisure activities, respectively). In this study, focus is placed on the effects of Internet use on non-work related or non-mandatory activity engagement because, as illustrated before, the work activities tend to be temporally and spatially fixed in an individual's activity-travel schedule. Accordingly, the time people spend on maintenance and leisure activities and related travel time on weekdays will be examined as the dependent variables in this research. Since subsistence/mandatory activities largely determine the patterns of undertaking other activities and associated trip-making (see Section 2.3.1.1), their duration is therefore considered as an independent variable in the model.

It is not surprising that only non-negative observations are included in the activity-travel variables, as they measure the amount of time-use which is recorded as the minimum value of zero in some cases. In terms of the maximum values, there are 26 adult cases reporting over-24-hours activity/travel duration for specific purposes or in total, though the Survey asked individuals to provide their travel information on one day before the survey date. The 26 cases were not considered in the analysis, as this study only examines individuals' activity-travel time-use patterns over the course of one day. After removing irrelevant and missing data, the activity-travel dataset for analysis includes 15,190 adults in total.

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4.2.2 Use of the Internet

The information about individuals' use of the Internet can be found in the SHS main
dataset. In the survey, there are two questions for collecting such information. First, the
survey asks the householders whether or not each person in the household uses the Internet
for their personal (as opposed to work-related) purposes. If the answer is yes, and that
person is selected as the random adult, the survey then asks how many hours s/he spends
on the Internet for non-work purposes per week, with provision of five time-use intervals
for choosing: up to 1 hour, from 1 hour up to 5 hours, from 5 hours up to 10 hours, from 10
hours up to 20 hours, and over 20 hours. In order to obtain a variable directly measuring
individuals' time use on the Internet, these two questions were combined together to create
the categorical variable of *Internet use* with six categories: never use (corresponding to the
"no" answer of the first question implying that this person does not use the Internet), up to
1 hour, from 1 hour up to 5 hours, from 5 hours up to 10 hours, from 10 hours up to 20
hours, and over 20 hours.

4.2.3 Socio-demographics and residential location

Apart from the key variables of activity-travel time use and Internet use, six
socio-demographic variables have also been considered in model: number of children in
household, age, gender, number of cars, availability of valid driving licence, and annual
household income. Age, number of children, and cars in household are continuous

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variables, while gender and ownership of driving licence are binary variables. The annual

household income, however, is recorded in the SHS dataset as an ordinal variable with

income classes representing different levels of income. In addition, a categorical variable

of *residential locations,* including three location indicators (urban, town, and rural areas)

was created, based on the 8-fold urban/rural classification applied in the SHS. Table 4-1

displays all the predictors included in this study, as well as their distribution.

4.2.4 Worker ratio and household classification

Upon completion of the above data processing and the removal of missing values, all the

observations (15,190 adult cases) were then categorised based on their different household

employment situations. In the SHS data, 13 categories were applied to describe each

household member's (including the random adult's) economic status, for example,

self-employed, full-time employment, part-time employment, looking after home/family,

permanently retired from work, unemployed and seeking work, and schooling. The

workers considered in this study only included those with full-time and part-time jobs, or

who were self-employed. After determining the working status (worker or non-worker) of

each person, the overall working status of the household can be known. However, unlike

the practices of previous studies, (e.g. Scott & Kanaroglou, 2002; Srinivasan & Athuru,

2005) which simply used the number of workers in each household, this study used the

worker ratio to represent the household working status. This ratio was calculated by

dividing the number of adult workers by the total number of adults in the household and

was preferred because a relative ratio can facilitate comparison and classification across

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households with varying amounts of workers and household size. Accordingly, the whole sample was divided into four household groups based on the worker ratio to show household working status: 0 worker; less than 50% workers (<50%); 50% or more workers (≥50%); and 100% workers. Moreover, in order to model the different activity-travel behaviour of workers and non-workers in different types of households, people from the groups of less than 50% workers, and 50% or more workers were further divided into two subgroups: workers and non-workers. That is, six groups were created for this study: adults from zero-worker households; workers from households with less than 50% workers; non-workers from households with less than 50% workers; workers from households with 50% or more workers; non-workers from households with 50% or more workers; and adults from 100% worker households.

4.2.5 Descriptive statistical analysis

All the explanatory variables considered in this study, including socio-demographics, residential location, and use of the Internet, are summarised in Table 4-1, which also presents the descriptive statistics (mean, minimum and maximum) of each variable according to the different household and individual groups classified above. The statistics show that the average age of all adults in the sample is around 48 years old and workers are younger than non-workers on average. In particular, the group with the highest average age of adults is the zero-worker family group (63 years), which implies that they are likely to be retired. Generally, the number of female adults, which accounts for 55% of the total

Table 4-1 Descriptive statistics for each household and individual group

	Full Sample			0% Worker			< 50% worker						≥ 50% Worker						100% Worker		
							Worker			Non-worker			Worker			Non-worker					
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
Socio-demographics																					
Age	48.32	16.00	99.00	63.68	16.00	99.00	38.32	16.00	64.00	40.02	16.00	86.00	40.62	16.00	86.00	50.63	16.00	92.00	42.44	16.00	99.00
Gender (female =1)	.55	.00	1.00	.59	.00	1.00	.49	.00	1.00	.76	.00	1.00	.54	.00	1.00	.65	.00	1.00	.47	.00	1.00
No. of kids	.48	.00	6.00	.18	.00	6.00	2.17	.00	5.00	1.62	.00	5.00	1.04	.00	3.00	.21	.00	2.00	0.58	.00	5.00
No. of vehicles	1.09	.00	10.00	.59	.00	7.00	1.34	.00	4.00	1.22	.00	6.00	1.45	.00	10.00	1.38	.00	5.00	1.41	.00	6.00
Driving licence (own=1)	.76	.00	1.00	.55	.00	1.00	.89	.00	1.00	.72	.00	1.00	.89	.00	1.00	.66	.00	1.00	.85	.00	1.00
Income	4.48	1.00	8.00	2.74	1.00	8.00	5.22	1.00	8.00	5.01	1.00	8.00	5.75	1.00	8.00	4.85	1.00	8.00	5.66	1.00	8.00
£0-6,000	.05	.00	1.00	.13	.00	1.00	.01	.00	1.00	.02	.00	1.00	.01	.00	1.00	.03	.00	1.00	.02	.00	1.00
£6,001-10,000	.15	.00	1.00	.36	.00	1.00	.04	.00	1.00	.07	.00	1.00	.03	.00	1.00	.08	.00	1.00	.07	.00	1.00
£10,001-15,000	.19	.00	1.00	.31	.00	1.00	.16	.00	1.00	.12	.00	1.00	.09	.00	1.00	.16	.00	1.00	.17	.00	1.00
£15,001-20,000	.15	.00	1.00	.12	.00	1.00	.21	.00	1.00	.22	.00	1.00	.13	.00	1.00	.20	.00	1.00	.17	.00	1.00
£20,001-25,000	.12	.00	1.00	.04	.00	1.00	.16	.00	1.00	.18	.00	1.00	.15	.00	1.00	.20	.00	1.00	.15	.00	1.00
£25,001-30,000	.11	.00	1.00	.02	.00	1.00	.13	.00	1.00	.14	.00	1.00	.16	.00	1.00	.12	.00	1.00	.13	.00	1.00
£30,001-40,000	.14	.00	1.00	.01	.00	1.00	.16	.00	1.00	.13	.00	1.00	.25	.00	1.00	.12	.00	1.00	.17	.00	1.00
£40,001+	.09	.00	1.00	.01	.00	1.00	.13	.00	1.00	.12	.00	1.00	.18	.00	1.00	.09	.00	1.00	.12	.00	1.00

(Continued)

Table 4-1 Continued

| | Full Sample | | | 0% Worker | | | < 50% worker | | | | | | ≥ 50% Worker | | | | | | 100% Worker | | |
| | | | | | | | Worker | | | Non-worker | | | Worker | | | Non-worker | | | | | |
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
Residential locations																					
Urban	.64	.00	1.00	.68	.00	1.00	.62	.00	1.00	.55	.00	1.00	.62	.00	1.00	.61	.00	1.00	.65	.00	1.00
Town	.15	.00	1.00	.14	.00	1.00	.14	.00	1.00	.15	.00	1.00	.16	.00	1.00	.17	.00	1.00	.14	.00	1.00
Rural	.21	.00	1.00	.18	.00	1.00	.24	.00	1.00	.30	.00	1.00	.22	.00	1.00	.22	.00	1.00	.21	.00	1.00
Internet use																					
Never	.43	.00	1.00	.75	.00	1.00	.23	.00	1.00	.37	.00	1.00	.25	.00	1.00	.47	.00	1.00	.30	0.00	1.00
Up to 1 hour	.17	.00	1.00	.09	.00	1.00	.25	.00	1.00	.16	.00	1.00	.23	.00	1.00	.14	.00	1.00	.19	0.00	1.00
1 up to 5 hours	.24	.00	1.00	.09	.00	1.00	.34	.00	1.00	.27	.00	1.00	.33	.00	1.00	.22	.00	1.00	.30	0.00	1.00
5 up to 10 hours	.09	.00	1.00	.04	.00	1.00	.11	.00	1.00	.09	.00	1.00	.11	.00	1.00	.09	.00	1.00	.13	0.00	1.00
10 up to 20 hours	.04	.00	1.00	.02	.00	1.00	.04	.00	1.00	.07	.00	1.00	.05	.00	1.00	.04	.00	1.00	.06	0.00	1.00
Over 20 hours	.02	.00	1.00	.01	.00	1.00	.03	.00	1.00	.04	.00	1.00	.03	.00	1.00	.04	.00	1.00	.02	0.00	1.00
Sample size	15,190			4,247			1,150			555			3,345			797			5,096		

sample, is slightly larger than that of males. However, this gender ratio changes in the worker groups, where there is a greater proportion of males (just over 50%). Compared to other groups, people from the zero-worker households have the smallest average number of children under 16 in their families. As expected, people from the worker groups have more access to car use on average, and are more likely to hold a valid driving licence than those from the non-worker groups. Notably, compared to the other household groups, the households with zero workers have the lowest amount of car ownership on average (only 0.59); this level is also far lower than the average ownership across the 15,190 households sampled (1.09). Moreover, members of such households, who are non-workers without question, have the lowest rate of driver licensure of any of the household groups. It seems that the working status of both the individuals themselves and of their households largely determines their accessibility to a car and their travel mode choice. Household income is classified as eight levels, ranging from less than £6,000 to over £40,000. The average annual income for the full sample is between £15,001 and £25,000, and the households with zero workers have the lowest income on average, approximately between £6,001 and £15,000. In terms of residential location, most people (around 60%) live in urban areas, and the differences among the groups are not significant. As for Internet use, it seems that non-users represent the highest proportion (43%) in this survey sample, with some differences across groups. In general, workers are more likely than non-workers to use the Internet for personal purposes. No matter which group they belong to, the percentage of workers without Internet use is generally less than 30%. This is probably because it is easier for workers to get access to computers and the Internet due to their work demands. Among the people who use the Internet for personal purposes, the majority spend one to

five hours online per week, irrespective of the group they fall into. Only up to 10% of people with or without jobs spend over 10 hours per week on the Internet.

4.2.6 Data feature and use of the two-part model (2PM)

In this study, as the dependent variable, activity-travel behaviour, is measured by the time used for performing maintenance activities and leisure activities, it should be remembered that, on a given day, a person might not undertake all types of activities. After the aforementioned data preprocessing, it is found that roughly 36% and 44% of the individuals (random adults) in the sample did not perform any maintenance and leisure activities, respectively, on the day prior to the survey interview. As a result, in the dataset, a significant number of observations on both the activity duration and travel time are recorded as zero. As elaborated in Section 3.2.1, the two-part model (2PM), consisting of a probit model and a log-transformed OLS model, was applied to accommodate such data features. Since six adult groups were identified based on their different individual and household working status, the 2PM was run for each group as well as for the whole sample. In each group, the correlations are examined between a set of independent variables and four activity-travel dependent variables, namely, duration of maintenance and leisure activities, and time spent on travel for undertaking the two types of activities. Modelling was enabled by using the *Stata 13.0* software package. The model's results, together with the goodness-of-fit of the models, are presented and analysed in the following section.

4.3 Analysis Results and Discussion

This section is devoted to elaborating the key results of the modelling analysis and its findings. It also includes discussion of these findings and their implications for planning and policy making. Due to the complicated household and individual grouping involved in this study, result analysis and discussion will be conducted for each group as well as for the whole sample. Final conclusions will then be drawn by integrating the findings from individual group analyses.

4.3.1 The 2PM results

The estimation results and model goodness-of-fit indices are summarised and presented in the 2PM results tables. For the full-sample models, the results tables detail the outputs of each modelling stage (see Table 4-2 & Table 4-3), which consist of three parts. Part I displays the results of the probit model, which is applied to specify the first part of the 2PM, assessing the effects of explanatory variables, including socio-demographics, residential location, and use of the Internet, on people's decisions regarding activity participation and trip-making. This part also presents both the estimates of coefficients and the associated marginal effects (mfx). Part II shows the results of the OLS regression model, which only examines the cases with decisions to perform activities or make travels (i.e. non-zero observations). The coefficients presented in the tables are estimated according to the log-transformed dependent variables, namely, activity duration or travel

time. By taking log retransformation and combining the results of the two parts, the overall

relationship between predictors and individual activity-travel behaviour is illustrated by the

Table 4-2 Complete 2PM results of maintenance activity duration for whole sample

	Part I (activity participation) (Probit)			Part II (activity duration) (Log_OLS)		Overall (AME)	
	Coeff.	mfx	Std. err.	Coeff.	Std. err.	mfx	Std. err.
Socio-demographics							
Age	.006	.002**	.000	.003**	.001	.148**	.076
Gender (female =1)	.181	.059**	.007	.139**	.028	14.601**	1.733
No. of kids	. 087	.028**	.004	.102*	.056	2.803**	1.205
No. of vehicles	-.039	-.013**	.006	-.020**	.010	-1.757**	.847
Driving licence (own=1)	.020	.006*	.004	.137**	.068	4.096**	2.053
Income	.005	.003**	.001	.036*	.000	.487**	.230
Duration_sub	-.003	-.001**	.000	-.002**	.000	-.196**	.005
Residential locations							
(reference: Urban)							
Town	-.045	-.015*	.008	-.133**	.038	-9.130**	2.415
Rural	-.033	-.011	.009	-.182**	.035	-11.350**	2.176
Internet use							
(reference: Never)							
Up to 1hr	.058	.019**	.007	.037	.029	5.032**	.473
1-5 hrs.	.044	.015*	.008	.102**	.040	8.413**	2.487
5-10 hrs.	.122	.040**	.013	.131**	.060	11.627**	3.460
10-20 hrs.	.091	.030**	.015	.101**	.049	6.719**	1.897
Over 20 hrs.	-.007	-.002	.023	.056	.100	3.213	1.018
_cons	-.143**		.024	4.615**	.072		
Sample size		15,190		9,721		15,190	
(Pseudo) R^2		0.166		0.118			
RMSE				1.016			

Notes: * Statistically significant at the 10% level.

      ** Significant at the 5% level.

average marginal effects (AME) reported in Part III of the results tables. In addition, the

standard error, which can measure the precision of the coefficient estimation, is also

Table 4-3 Complete 2PM results of maintenance travel time for whole sample

	Part I (activity participation) (Probit)			Part II (activity duration) (Log_OLS)		Overall (AME)	
	Coeff.	mfx	Std. err.	Coeff.	Std. err.	mfx	Std. err.
Socio-demographics							
Age	.005	.002**	.000	-.003**	.001	-.033**	.015
Gender (female =1)	.164	.055**	.007	-.011	.019	2.486**	.726
No. of kids	.073	.025**	.004	.154**	.088	.579**	.290
No. of vehicles	-.039	-.013**	.006	-.014	.027	-.599*	.335
Driving licence (own=1)	.021	.001*	.001	-.032**	.013	-1.768**	.378
Income	.003	.001	.002	.016**	.006	.534**	.231
Duration_sub	-.002	-.001**	.000	-.001**	.000	-.086**	.002
Residential locations							
(reference: Urban)							
Town	-.064	-.022	.022	.064**	.024	1.723**	.627
Rural	-.080	-.027**	.009	.111**	.024	3.974**	1.708
Internet use							
(reference: Never)							
Up to 1hr	.080	.024	.017	.048	.043	2.155	.961
1-5 hrs.	.059	.018**	.009	.066**	.028	4.368**	1.095
5-10 hrs.	.098	.030**	.013	.069**	.027	4.507**	1.111
10-20 hrs.	.059	.018**	.008	.063**	.031	4.164**	.891
Over 20 hrs.	-.058	-.017	.021	-.008	.064	-1.078	2.404
_cons	.528		.056	3.903	.048		
Sample size		15,190		9,721		15,190	
(Pseudo) R^2		.158		.116			
RMSE				.832			

Notes: * *Statistically significant at the 10% level.*

   ** *Significant at the 5% level.*

reported for each coefficient and marginal effect estimate in the detailed 2PM results tables. When explaining the model results of the six household/individual groups, however, a "simplified" result table (see Table 4-5 and Table 4-6) is used, which still consists of three parts, but only presents the key model outputs that are important for analysis (i.e. coefficient estimates from the probit and the OSL regression models, and the AME).

4.3.2 Analysis for the whole sample

The results from the full-sample models are presented in Tables 4-2, 4-3 and Table 4-4. It is manifest from Table 4-2 that almost all the socio-demographic characteristics show significant correlations with the duration of maintenance activities. For instance, older adults tend to spend more time on maintenance activities, which implies that younger people are likely to dedicate more time to other activities, such as work, study and recreation. Compared to males, females generally spend more time undertaking maintenance tasks, which reflects the traditional gender roles in taking responsibility for such tasks. Furthermore, households with more children generate more maintenance activities, probably due to the extra tasks involved in escorting children to/from schools and because more shopping is required. People from households with more vehicles tend to be involved in fewer maintenance activities, possibly because household members are more likely to share the tasks due to the increased car accessibility; thus, fewer tasks are performed by each member. However, people who have a valid driving licence seem to undertake more maintenance tasks than those without a licence. This implies that increased

access to vehicles could generate more physical activity participation. In addition, high-income people are inclined to spend more time on such activities than the poor. Apart from the socio-demographics, which is the key determinant of opportunities to perform other activities, the duration of subsistence activities (*Duration_sub* shown in the table) is negatively associated with that of maintenance activities. In terms of the effect of residential location, compared to people living in urban areas, those living in towns and rural areas have a shorter activity duration. This finding seems sensible, as people who live in the suburbs or remote areas generally have fewer opportunities to perform daily maintenance activities due to their having less accessibility to shops, banks and other facilities.

As for the relationship between ICT use and activity-travel behaviour, Table 4-2 reveals that there is a significant complementary effect of Internet use on duration of maintenance activities. More specifically, compared to people who never use the Internet, people who use it for personal purposes tend to spend more time undertaking maintenance activities. This complementary effect on activity participation peaks at the 5-to-10-hour usage. However, if a person spends over 20 hours online, his/her engagement in maintenance activities is not significantly distinct from that of non-users. The results from the probit model also indicate that use of the Internet facilitates personal decisions to undertake maintenance activities.

Table 4-3 presents the results of the maintenance travel time-use model for the whole sample. Similar to the results derived from the activity model, most socio-demographics

and participation in subsistence activities significantly influence people's trip making for maintenance activities, and such effects are generally analogous to those revealed by the activity analysis above. However, unlike the positive effect of age on activity duration detected before, older people tend to spend less time on travel for maintenance activities. However, the probit model reveals the opposite effect of age on the decisions to make trips. This may imply that although older adults are more likely to undertake maintenance activities and to make associated trips, they tend to make short-distance trips with shorter durations due to their physical situations. Since people who hold a valid driving licence have greater access to cars, they tend to spend less time travelling. Furthermore, people who live in towns and rural areas have a longer travel duration compared to those living in cities. As facilities like shops and banks cannot easily be accessed by those living in more remote locations, it is not surprising that these people need to spend more time on travel to reach these amenities. As for the Internet-induced impact on the duration of travel for maintenance tasks, the effect of complementarity is also found. It seems rational that more activity undertaking results in more associated travel. However, unlike the situation with activity duration, this complementary impact on travel time does not seem to markedly increase as more time is spent on the Internet. In particular, no significant effect is found when people only spend less than one hour online, which means that non-users of the Internet and people with low-frequency usage may spend similar amounts of time travelling. Similar results can also be derived from the probit model.

As for people's time use on leisure-related activities and travel, significant correlations with some socio-demographics are found, according to Table 4-4. Age is negatively

correlated with the duration of both activity participation and travel for leisure purposes, which verifies the findings revealed before that younger people tend to spend more time on leisure and recreational activities. This negative correlation is also detected between the

Table 4-4 2PM results of leisure activity duration and travel time for whole sample

	Activity Duration			Travel Time		
	Part I Coeff.	Part II Coeff.	AME	Part I Coeff.	Part II Coeff.	AME
Socio-demographics						
Age	-.002**	-.005**	-.340**	-.002**	-.001	-.0540**
Gender (female =1)	-.009	.019	.486	-.012	-.090**	-2.192**
No. of kids	-.073**	-.055**	-7.508**	-.085**	-.057**	-3.075**
No. of vehicles	.051**	.011	1.027**	.047**	-.018	.654
Driving licence (own=1)	.090**	-.114	-.843	.112**	-.015	2.140**
Income	.022**	.010*	1.616**	.017	.012	.122
Duration_sub	-.002**	-.001**	-.152**	-.002**	-.001**	-.063**
Residential locations						
(reference: Urban)						
Town	-.002	-.090**	-5.112*	.019	.001	.426
Rural	-.047*	-.112**	-9.109	-.062**	.149**	1.847**
Internet use						
(reference: Never)						
Up to 1hr	.101**	-.0412	3.812	.104**	.066	3.721
1-5 hrs.	.110**	-.060	3.346	.117	.082**	4.328*
5-10 hrs.	.043	.012	3.297	.047	.025	1.562
10-20 hrs.	.056	-.014	2.677	.070	.101	3.711
Over 20 hrs.	.082	-.160	-3.929	.108	.101	4.521
_cons	-.315**	5.300**		-.229**	3.840**	
Sample size	15,190	8,521	15,190	15,190	8,521	15,190
(Pseudo) R^2	.093	.062		.091	.054	
RMSE		1.044			.935	

*Notes: * Statistically significant at the 10% level.*

*** Significant at the 5% level.*

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number of kids in a household and leisure-related activity-travel time use; this is reasonable as more time is dedicated to childcare, which may be seen as extra maintenance activities. Household income, by contrast, is positively correlated with both probability (shown in the probit model result) and duration of undertaking leisure activities, revealing that richer people are more capable of affording such activities. Similar to the situation with maintenance activity-travel, the duration of subsistence activities is negatively correlated with that of leisure ones and travel time. However, according to Table 4-4, no significant effect is found for the effect of Internet use on activity-travel time use for leisure purposes. In fact, modelling results show that none of the leisure-related models for the six household/individual groups detect significant Internet-induced impacts on leisure activity duration and travel time. These insignificant relationships possibly result from complementary and substitutive effects cancelling each other out, leading to a situation of net neutrality. In addition, considering the years 2005 and 2006, it is also possible that the Internet had not yet significantly penetrated or influenced individuals' leisure life, regardless of their working status. In the following analysis, therefore, presentation and explanation of the results of leisure models are omitted.

4.3.3 Validation of the segmentation-based modelling strategy

Prior to running the 2PM for the six groups separately, the modelling strategy, which examines the activity/travel-related relationships among different population segments, needs to be statistically validated. If the models, which consider the differences in the activity/travel-related relationships according to household working status, as well as the

effects caused by household working status, perform significantly better than the previous

models without such considerations, the segmentation-based modelling strategy would be

statistically preferred. The validation was performed by applying the likelihood ratio test

(LRT), which is a statistical test used for comparing the goodness-of-fit (i.e. log-likelihood

values) between two nested models. The test statistics can suggest whether or not a

relatively more complex model with additional parameters fits the data significantly better

than a simpler one. In this situation, the simpler models to be tested were presented and

estimated as above (Table 4-2 and Table 4-3), while the more complex models were

developed by additionally including five dummy variables representing the household

groups (with one group omitted), as well as a set of items created by interacting the

dummy variables with all the predictors in the simpler models. After running the two types

of models, their log-likelihood values were estimated as a part of the model results, and are

presented in Table 4-5. It is manifest that in either modelling case (i.e. explaining

Table 4-5 Comparison of model fit between the simpler and the more complex models

	Dependent variable: maintenance activity duration		Dependent variable: maintenance travel time	
	The simpler model (*estimated as Table 4-2*)	The more complex model	The simpler model (*estimated as Table 4-3*)	The more complex model
Log-likelihood	-16,753.452	-16,532.691	-16,670.573	-16,462.464
Likelihood ratio test (LRT) statistic (χ^2)	441.522 (d.f. =75, p-value= .000)		416.218 (d.f. =75, p-value= .000)	

maintenance activity duration or travel time), the log-likelihood value of the more complex

model is higher than the simpler model's, which suggests that the more complex model

may fit the data better. The significance of the observed difference in model fit can be

tested according to the LRT statistic, which was calculated based on each model's log-likelihood value and follows a chi-square (χ^2) distribution. Since the associated p-value is less than 0.05 in each modelling case, the more complex models are proven to fit the data significantly better. The choice of the modelling strategy based on market segmentation is, therefore, statistically validated.

4.3.4 Analysis for the groups of zero and less than 50% worker

The model results for the six groups, which were classified based on the different household worker ratio, are shown in Table 4-6 and Table 4-7, with the dependent variables of maintenance activity duration and travel time, respectively. As mentioned before, the two tables contain the "simplified" 2PM results, which only report the coefficient estimates and the average marginal effects (AME), as well as their statistical significance. The varying effects of Internet use on activity-travel time use for the six groups are then summarised in Table 4-8.

For the adults from households with zero workers, the complementary effect of Internet use on activity-travel time use is quite analogous to the effects found in the full-sample models. The Internet users generally spend more time performing maintenance activities than the non-users, except for those dedicating over 20 hours weekly to the Internet. The same effect on travel time is also detected as a result of using the Internet. In terms of the influences of socio-demographic features, gender no longer significantly determines

Table 4-6 2PM results of maintenance activity duration for six adult groups

	Models (dependent variable: maintenance activity duration)																	
	0%			< 50% worker						≥ 50% Worker						100%		
	Worker			Worker			Non-worker			Worker			Non-worker			Worker		
	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME
Socio-demographics																		
Age	.002*	.004**	.237**	.013**	-.004	.256*	.001**	.020**	.442**	.005**	.002	.235	-.000	.007**	1.079**	.003**	-.005	-.101
Gender: female	.041	.237*	19.790	.488**	.024**	16.640**	.298**	.594	21.618	.265**	-.001	8.409**	.080**	-.019	2.469	.100*	.045	3.738
No. of kids	.085**	.104**	1.568**	.123**	-.002	3.847	.043*	.132**	2.697**	.033*	.066**	.119*	.076**	.209*	8.001**	.067	.215	4.682
No. of vehicles	-.063*	-.056	-6.992**	.081	.031	3.922	-.113*	.072	-1.279*	-.068**	.011	-1.722	.010	-.063**	-4.265**	-.043*	-.002	-1.769**
Owning licence	-.031	.020	.234	.031**	-.374*	1.674*	.022	.041*	6.843	.269**	-.358**	-5.810	.064*	-.314**	-6.772	.037	-.194**	2.941*
Income	.021	.020**	.062**	-.023	.035	-2.095	.014	.019**	2.916**	.034**	.020**	1.873**	.008	-.018	-1.576	.018*	.025*	.398
Duration_sub	-.003**	-.001*	-.202*	-.002**	-.002	-.162*	-.006**	-.002**	-.543**	-.003**	-.002**	-.164**	-.004**	-.000	-.255**	-.003**	-.001**	-.150**
Locations																		
(urban referenced)																		
Town	-.019	-.101**	-8.472**	.072	-.186	-5.633	-.047**	-.125**	-6.010**	-.082*	-.202**	-9.477**	-.192**	-.134*	-6.210**	-.072	-.201**	-11.424**
Rural	-.017	-.195**	-15.536**	-.012	-.013	-.936	.117	-.010*	-3.276	.002	-.237**	-10.740**	-.075	-.180**	-4.744*	-.084**	-.225**	-12.937**

(Continued)

Table 4-6 Continued

	Models (dependent variable: maintenance activity duration)																	
	0% Worker			< 50% worker						≥ 50% Worker						100% Worker		
				Worker			Non-worker			Worker			Non-worker					
	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME
Internet use																		
(reference: Never)																		
Up to 1 hr.	.0150**	.023	2.617**	.076	.217	4.158	.085**	.079*	10.636**	.095**	.054	6.048**	.075	.049**	7.438**	.107*	.068**	5.119**
1 up to 5 hrs.	.058**	.087**	7.778**	.077	.145	2.777	.102**	.275**	23.785**	.167**	.143**	10.487**	.128**	.105**	13.230**	.156**	.133**	6.688**
5 up to 10 hrs.	.128**	.312**	29.248**	.264	.329**	8.510*	.134**	.353**	45.993**	-.022**	-.050**	-1.366**	.186**	.136**	15.694**	.076**	.125	-1.113
10 up to 20 hrs.	.094*	.242**	18.261**	-.110	.044	-1.638	.003	.199**	12.207*	-.064**	-.063**	-4.766**	.038*	.021	5.765	-.028*	-.037**	-4.190**
Over 20 hrs.	-.030	.117	7.661	.035	-.379	-7.063	-.661**	-.011*	-10.781**	-.141	-.107**	-7.606**	-.475**	-.075	-9.334	-.310	-.042**	-8.407**
_cons	.224**	4.389**		-.827**	4.778*		.500**	5.104**		-.635**	4.347*		.356**	5.338*		-.373**	4.772**	
Sample size	4,247	2,435	4,247	1,150	796	1,150	555	368	555	3,345	2,088	3,345	797	625	797	5,096	3,409	5,096
(Pseudo) R^2	.163	.110		.170	.080		.172	.121		.165	.119		.155	.117		.163	.124	
RMSE		1.084			1.213			1.134			1.049			1.114			1.156	

Notes: * Statistically significant at the 10% level.

　　　 ** Significant at the 5% level.

Table 4-7 2PM results of maintenance travel time for six adult groups

	Models (dependent variable: maintenance travel time)																	
	0%			< 50% worker						≥ 50% Worker						100%		
	Worker			Worker			Non-worker			Worker			Non-worker			Worker		
	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME
Socio-demographics																		
Age	.001*	-.003**	-.081**	.010	-.008	-.097	.000	-.010**	-.526**	.004*	-.001	.056	-.005	-.007**	-.403**	.002	-.001**	-.001**
Gender: female	.044	-.003	.768	.383**	-.085	4.959*	.177**	.268**	16.679**	.282**	.032**	4.190**	.055**	.032	2.513	.033*	.047	2.474
No. of kids	.081**	.019	2.427**	.097**	.046	1.194	-.067	.023**	.978**	.032	-.001	.600	.043*	.132*	6.135**	.014	.025	3.087
No. of vehicles	-.054**	-.027*	-2.219**	.086	.022	2.298	-.129*	.058	.648	-.077**	-.019	-.466	.032	-.023**	-1.767*	-.046*	-.002	-.971
Owning licence	.009	.011	.632	.088*	.049*	.574*	.006	-.046**	-2.197**	.256*	-.019**	-.604**	.106	-.036*	-.894*	.090*	-.043*	-.508**
Income	.026**	.002*	.437*	.007	.018	.656	-.014	.041*	-.392	.035**	.016**	1.152**	.022**	.001	.381	.016**	.027**	.993**
Duration_sub	-.003*	-.001*	-.108*	-.002**	-.001	-.081	-.004**	-.001	-.104	-.002**	-.001**	-.078**	-.004**	-.002**	-.172**	-.002**	-.001**	-.063**
Locations																		
(urban referenced)																		
Town	-.043	.075**	1.598**	-.011	.039	.910	-.069*	.099**	3.277**	-.060	.028*	-4.874	-.159	-.032	2.078	-.107**	-.082	1.261
Rural	-.054**	.104**	3.292*	-.114	.252**	5.038**	-.078**	.188**	10.046**	-.049**	.086**	3.568**	.028*	.038**	2.308*	-.142**	.181**	1.555**

(Continued)

Table 4-7 Continued

| | 0% Worker | | | < 50% worker | | | | | | ≥ 50% Worker | | | | | | 100% Worker | | |
| | | | | Worker | | | Non-worker | | | Worker | | | Non-worker | | | | | |
	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME	Part I Coeff.	Part II Coeff.	Overall AME
Internet use																		
(reference: Never)																		
Up to 1 hr.	.017	.148*	6.582*	.048	.062	1.382	.231*	.073	2.218*	.126*	.073	1.286	.005	.013*	2.654**	.061	.016	.846
1 up to 5 hrs.	.019**	.160**	6.724**	.013	.090	2.133	.205**	.105**	2.866**	.051	.121	.908	.038**	.116**	5.532**	.090*	.013	1.138
5 up to 10 hrs.	.068**	.219**	9.218**	.039*	.148	5.026	.354**	.169**	6.477**	-.035**	-.071**	-.866**	.052**	.105**	5.204**	.163	.026	1.360
10 up to 20 hrs.	.059**	.201**	9.055**	-.230	-.309	-13.355	.104	.094*	2.227*	-.053**	-1.003**	-1.453**	.013**	.047	.704	-.070**	-.048**	-2.309**
Over 20 hrs.	-.056	.086	2.503	-.075	-.640**	-19.855**	-.469**	-.121**	-3.764**	-.098**	-1.355*	-3.574**	-.042	-.144*	-3.321	-.108**	-.099**	-4.982**
_cons	.424**	3.846**		-.616**	4.005**		.899**	4.129**		-.403**	3.721**		.931**	4.020**		-.082	3.719**	
Sample size	4,247	2,435	4,247	1,150	796	1,150	555	368	555	3,345	2,088	3,345	797	625	797	5,096	3,409	5,096
(Pseudo) R²	.144	.112		.173	.078		.168	.117		.158	.108		.136	.121		.147	.121	
RMSE		.784			.907			.844			.875			.842			.831	

Notes: * Statistically significant at the 10% level.

** Significant at the 5% level.

activity-travel patterns given that, as all household members are non-workers with a flexible time schedule, they tend to share the maintenance tasks instead of only females taking on the responsibilities. Although adults in these households are not workers, they may be attending college/school as students or attending some training schemes, both of which are also commonly classified as subsistence activities (e.g. Lu & Pas, 1999; Srinivasan & Bhat, 2005). Hence, subsistence activities still passively influence their maintenance-related activity-travel time use even though this influence is marginally significant.

For the group of less than 50% workers in a household, the situation is a little different. It is clear from Tables 4-6 and 4-7 that the Internet-induced effects are not significant on either activity duration or travel time for the workers in this household group. The probit results do not indicate a significant effect on activity-travel decisions, either. Nevertheless, for the non-workers in these households, a significant complementary effect caused by Internet use is detected. This phenomenon could be explained by the intra-household interactions introduced before (see Section 2.3.1.3), which involve allocation of activities to household members to meet household needs under temporal, spatial or resource constraints. Since in these families most members are non-workers, the household maintenance tasks are, therefore, naturally allocated to the non-working members to perform, without concerning the workers. It may not be strange that there is no relationship between Internet use and workers' activity-travel behaviour as they seldom undertake maintenance activities on weekdays. Besides Internet use, most of the socio-demographics and subsistence activity engagement also have insignificant impacts on workers'

maintenance-related mobility patterns. For the non-workers, although the significant complementary effect of Internet use is found, this effect will turn into substitution if people spend more than 20 hours online. It seems that because of the attendant time constraints, if people spend too much time online, they tend to use the Internet (e.g. teleshopping and e-banking) to substitute their physical activity engagement and associated travel. This result is consistent with previous literature on the subject (e.g. Lu & Pas, 1999; Golob, 2000; Senbil & Kitamura, 2003).

4.3.5 Analysis for the groups of 50% or more workers and 100% workers

As the ratio of workers in a household increases, the time constraints imposed by workers' work activities will not only influence their own activity-travel patterns but also those of other non-workers in the household in terms of non-work activity participation and travel. This was also revealed by many studies on intra-household interactions (e.g. Golob & McNally, 1997; Scott & Kanaroglou, 2002). Hence, the Internet-induced effects may differ from those found in families with fewer workers. For instance, unlike the situation in households with a lower worker ratio, a significant effect is detected of Internet use on the maintenance activity-travel behaviour of workers who come from households with 50% or more workers. This means that workers in this household type undertake the maintenance activities as the non-workers do. This is sensible because if most household members are workers, the smaller amount of non-working members may not be able to perform all the maintenance tasks for the whole family, and such tasks are then shared by both workers

and non-workers. For the workers, however, the complementary effect of Internet use is only influential on their activity performing if they spend no more than 5 hours online for personal purposes (Table 4-6). If over 5 hours are dedicated to the Internet, the effect will become substitutive. As elaborated before, the substitutive effect of Internet use on activity-travel behaviour is usually generated by people's attempts to replace their out-of-home activities and related travels with virtual activities online, especially when they are confronted with time constraints. It seems that workers are more likely to adopt this substitution if they spend too much time on the Internet due to the additional time constraints imposed by their work. Besides, they may also transfer their maintenance tasks to other non-workers in order to ensure that there is enough time for work, which is a typical type of intra-household interaction. This could explain the appearance of substitutive effects on both the activity duration and travel time when more than 5 hours are spent online by workers. As shown in Table 4-7, however, with up to 5 hours' use of the Internet, workers' trip making for maintenance activities does not increase significantly, though the complementary effect of Internet use on their activity engagement is found to be significant. A plausible explanation could be the adoption of a trip-chaining strategy, as people always try to spend the least amount of travel time possible to complete daily activities, thereby enhancing travel efficiency and realising utility maximisation, especially in the situation where work imposes more intensive time constraints (Kondo & Kitamura, 1987; Bhat, 1997; Golob, 2000). In contrast, these Internet-induced effects on non-workers' activity-travel patterns are akin to those identified in the group of less than 50% workers, with the difference that the complementary effect disappears when over 10 hours are spent online. This change in effect is probably because, as the minority in a household,

non-workers were already the main undertakers of maintenance tasks, and time constraints may not allow them to perform too many extra maintenance activities facilitated by Internet use.

Adults from households with 100% worker tend to share the maintenance tasks, as there are no non-working members to be the main undertakers of maintenance in their households. Similar to the situation with the zero-worker household group, maintenance tasks seem to be shared equally across gender in households without significantly concerning the female members. Table 4-6 and Table 4-7 show that their activity engagement and trip making is also influenced by Internet use in different ways. The complementary Internet-induced effect on their activity decision and duration is only found to be significant when they use the Internet for up to 5 hours a week; if more than 5 hours are spent online, the effects will turn into substitution (see Table 4-5). The substitutive impact also significantly influences people's travel time if over 10 hours are dedicated to the Internet (see Table 4-7). Such changeable effects are analogous to those detected in workers from families with 50% or more workers. Apart from the substitution of online activities like e-shopping and e-banking for physical maintenance activities and trips, another possible explanation for the substitutive effects induced by spending much time online could be that workers reschedule their non-work activities to ensure their normal work duration. As much research indicates, households with multiple workers tend to schedule maintenance activities on weekends (e.g. Bhat & Misra, 1999; Srinivasan & Bhat, 2005; Srinivasan & Athuru, 2005). In addition, just as in the situation with the workers of the 50%-or-more group, both the probability of trip-making and travel duration will not be

affected significantly even though the activity duration increases when fewer than 5 hours are dedicated to the Internet, possibly due to the adoption of a trip-chaining strategy.

Table 4-8 Summary of the Internet-induced effects on maintenance activity-travel patterns for six groups

	0% Worker	< 50% worker			≥ 50% Worker				100% Worker	
		Worker	Non-worker		Worker		Non-worker		Worker	
Effects on activity duration	+	N	Within 20 hrs. spent online	+	Within 5 hrs. spent online	+	Within 10 hrs. spent online	+	Within 5 hrs. spent online	+
			Over 20 hrs. spent online	−	Over 5 hrs. spent online	−	Over 10 hrs. spent online	N	Over 5 hrs. spent online	−
Effects on travel time	+	N	Within 20 hrs. spent online	+	Within 5 hrs. spent online	N	Within 10 hrs. spent online	+	Within 10 hrs. spent online	N
			Over 20 hrs. spent online	−	Over 5 hrs. spent online	−	Over 10 hrs. spent online	N	Over 10 hrs. spent online	−

Note: '+' stands for complementary effects, '−' stands for substitutive effects, 'N' means no significant effects.

4.4 Summary and Policy Implications

4.4.1 Conclusion of analysis

The analysis above empirically examines how time spent on the Internet for personal purposes affects adults' non-mandatory activity (maintenance and leisure activities) engagement and associated travel, and how such effects vary according to household working status defined by worker ratio. The activity-based time-use approach is employed to model the interactions between Internet use, socio-demographics, and residential

location and individuals' activity-travel behaviour represented by activity duration and travel time. In order to correct the bias and inefficiency caused by a large number of zero observations in the activity-travel variables, the 2PM method, which consists of a probit model and an OLS regression model with log-transformation, is applied to get the estimates of regression coefficients and marginal effects, for both the full sample and the six groups classified by household worker ratio and an individual's working status. According to the modelling results, presented and analysed in depth above, conclusions can be drawn by answering the research questions proposed at the beginning of this chapter as follows:

*a) What are the effects of the amount of time spent on the Internet on individuals' time use for **maintenance** activities and associated travel?*

The amount of time people spend on the Internet has a significant effect on both the duration of undertaking maintenance activities and associated travel time use, and their relationships are based on complementarity. More specifically, people who spend more time online for personal purposes tend to have a longer duration of performing maintenance tasks compared to non-users of the Internet. However, if over 20 hours per week are spent on the Internet, the complementary effects will no longer be significant due to the time budget effect. This complementary relationship is also detected between Internet use and the duration of travel for maintenance purposes, though travel time does not grow proportionately with the increase in activity duration caused by Internet use.

b) What are the effects of the amount of time spent on the Internet on individuals' time use

    *for **leisure** activities and associated travel?*

No significant effects of Internet use on the duration of activity undertaking or trip making for leisure purposes are found in either of the models – for the full sample and for six adult groups. This means that time spent on the Internet for personal purposes, overall, has no impact on people's leisure-related activity-travel time use. It is possibly the concurrence of both complementary and substitutive effects caused by Internet use which leads to an effect of neutrality. Another plausible explanation could be that the Internet had not yet significantly penetrated individuals' leisure life by the year 2005/06, neither had their participation in out-of-home leisure activities been significantly influenced by in-home ones fuelled by the Internet (playing video games, enjoying music and movies online, online chatting, etc.).

c) Do these effects vary according to household working status? If so, to what extent do the

    effects vary according to household working status?

The results also reveal that these Internet-induced effects vary according to household working status, as summarised and presented in Table 4-8. In other words, household working status could influence the complementary relationship between Internet use and people's maintenance activity-travel time use, and this influence is characterised by intra-household interactions and individuals' employment statuses which impose different constraints on people's non-work activity-travel patterns. First, by determining activity

allocations among household members, household working status could affect the significance of the Internet-induced impacts. Since non-workers are the main undertakers of maintenance activities, Internet use always has significant effects on their maintenance-related activity-travel behaviour, despite the group differences. By contrast, as workers do not always perform maintenance tasks, the significance of such Internet-induced impacts depends on whether they perform the tasks or not, and they are more likely to perform them as the household worker ratio increases. Second, people may use the Internet and online services, such as e-shopping and e-banking, to substitute their physical maintenance activities and travel, especially workers who are confronted by intensive time constraints mainly imposed by their work. Therefore, the effects of Internet use become substitutive if people spend too much time online for non-work purposes, particularly workers who undertake maintenance activities. Third, the trip-chaining strategy, which is largely encouraged by time constraints and thus is frequently adopted by workers to enhance travel efficiency, could lead to workers' travel time becoming less sensitive to Internet-induced complementary effects. In other words, travel time may not grow as activity engagement increases under the complementary effects of Internet use.

Apart from the effect of Internet use, which is the primary focus of this study, conclusions can also be drawn regarding the relationships between socio-demographics, as well as residential location, and non-mandatory activity-travel patterns:

• *Age*

While older people tend to dedicate more time to maintenance activities, younger adults

generally allocate more time to leisure. However, although older adults are more likely to undertake activities and travels for maintenance purposes, they tend to make short-distance trips with less travel duration, which can possibly be ascribed to their physical situation.

• *Gender*

In general, females spend more time undertaking maintenance tasks than males do, reflecting the traditional gender roles in taking responsibility for these tasks. This traditional task allocation according to gender, however, is no longer seen in the households where the members are all workers or non-workers. Maintenance tasks tend to be equally shared by household members irrespective of gender when members have the same working status. It seems that working status to a large extent determines the traditional gender roles in the allocation of household maintenance activities, as males are generally more likely to be workers in a household than females.

• *Number of children*

In addition, in households with more children, an individual (adult) will generally spend more time on maintenance-related activities and travel and less time on leisure-related ones since s/he may be involved in more extra maintenance tasks, such as childcare-related activities (e.g. escorting children to/from schools and shopping more often).

• *Household income*

Compared to those with low household income, high-income individuals tend to have a higher probability and a longer duration of undertaking activities and trips for both

maintenance and leisure purposes as they are better able to afford non-mandatory activities in terms of money and time available.

• *Subsistence activity*

Acting as a "peg" which characterises people's daily mobility patterns (Cullen & Godson, 1975), participation in subsistence activities is always negatively correlated with non-mandatory activity undertaking in terms of time use. When more time is dedicated to subsistence/mandatory activities, less time is left to undertake maintenance or leisure ones.

• *Residential location*

Compared to urban dwellers, people living in remoter areas (town and rural areas) generally spend less time on daily maintenance activities, but more time on travel for undertaking activities, since these areas have less accessibility to amenities and facilities (e.g. stores and banks).

4.4.2 Policy and planning implications

ICT has the potential to reduce or even substitute people's physical travel since they can provide alternatives to face-to-face communication. This potential is appealing for transport planners and policy makers, who have been desperately searching for methods to reduce traffic volumes, relieve congestion and pollution, and save energy, all of which require changes in behaviour. As reviewed before, many "smart" policy strategies, which

highlighted the role of ICT in achieving sustainability in the transport sector and in urban areas, have already been developed and practised, with both satisfying and unsatisfying results obtained. However, as the results of this study and those of many recent studies reveal, the potential of ICT to substitute travel may have been overestimated; in fact, they may even have complementary effects on travel. From the activity-travel perspective on which this study is based, use of ICT may increase people's engagement in certain activities in the physical world, thereby generating trips for undertaking these activities. The situation, therefore, is complicated: while potentially substituting physical activities with virtual ones (e.g. e-shopping, e-banking and online gaming), ICT can also facilitate participation in physical activities by, for example, increasing accessibility to places, people, information, events, goods or services (Mokhtarian, 2009). Due to the complicated mechanisms by which ICT affect activity-travel patterns, it is expected that people will manifest different behavioural responses to ICT adoption according to their personal and household situations. This study exemplifies the varying effects of ICT use on activity-travel behaviour according to household working status. Based on this exemplification, planners and policy-makers are advised to seek more accurate and holistic predictions of travel demand for specific individual and household types when determining the strategic role ICT might play in policy making for sustainable mobility and urbanism.

Chapter 5 Temporal Dynamics in the Relationship Between Internet Use and Activity-Travel Behaviour

Chapter 4 revealed the diversity of the interactions between ICT and activity-travel behaviour from a cross-sectional and static perspective. However, as previously discussed in Chapter 2, insufficient attention in this research area has been dedicated to the temporal dynamics in these ICT-travel relationships. Since ICT have recently been under rapid development, with increasingly wider applications, they have penetrated ever deeper over time into people's daily lives, leading to a trend of digitalised life (Reed, 2014). Likewise, due to this technological evolution, changes in people's ICT-usage patterns over time can also be expected. A good illustration of this is the expansion of the e-commerce market, in which transaction strategies are evolving from the model of B2B (business-to-business), via B2C (business-to-customer) to the model of C2C (customer-to-customer) (Basole & Rouse, 2008). As a consequence, individuals are finding e-commerce and online transactions easier to use and are becoming more dependent on them. From a longitudinal perspective, this rapid evolution in technology causes dynamic effects on people's lifestyles and behaviour, including on their mobility patterns. However, there appears to be a dearth of transport studies taking such a longitudinal point of view to examining the ICT-travel relationship. This is partially due to the lack of data sources containing either repeated information for the same individuals (panel data) or repeated samples from the same population (repeated cross-sectional data), and partially as a result of the difficulties

in capturing the rapid evolution of ICT functionalities and adoption.

Another topic which is increasingly being discussed in current travel behaviour studies is generational differences, with focus predominantly placed on the millennial generation. As reviewed in Section 2.3.1.5, it has been well documented that millennials exhibit mobility patterns which are distinct from those of their predecessor generations (Dutzik et al., 2014; Garikapati et al., 2016). For instance, they are generally found to exhibit lower rates of both possessing a driver's license and of car ownership (Delbosc & Currie, 2013; Dutzik et al., 2014; Thakuriah et al., 2010), they drive less (Frändberg & Vilhelmson, 2013; McDonald, 2015; Kuhnimhof et al., 2012), they use alternative modes more often (Blumenberg et al., 2012; Dutzik et al., 2014; Garikapati et al., 2016), and they undertake fewer trips and travel fewer miles on a daily basis (McDonald, 2015; Polzin et al., 2014) compared with earlier generations. In addition, as "digital natives" who were born and grew up in an era of ubiquitous technology, millennials show heavy reliance on ICT and tend to adopt ICT in every aspect of their daily lives (including daily mobility), which greatly differs from the ICT usage of non-millennials, or "digital immigrants", who are more likely to treat ICT as a useful tool instead of an essential component of daily life. Considering the unique traits of both their mobility patterns and their ICT use patterns, millennials' behavioural responses to the adoption of ICT in terms of activity participation and trip making may also be distinct. This chapter will investigate this issue.

Overall, following the approach adopted in Chapter 4, this chapter attempts to examine the evolution of the interactions between ICT adoption and activity-travel behaviour over time,

and how this evolution and these interactions distinctly occur among millennials, as required by **Objective B** of this thesis. This chapter begins by stating its research objective and questions in Section 5.1. The data sources adopted in this study, i.e. the 2005/06 Scottish Household Survey (SHS) and the iMCD Survey datasets, are then introduced in Section 5.2, with data preprocessing and variable formation explained. The results derived from the modelling analysis are subsequently presented in Section 5.3 along with discussion of research findings. Lastly, conclusions are drawn in Section 5.4 by summarising findings, and policy-making recommendations are proposed according to the findings.

5.1 Objective and Research Questions

The overall aim of this study is relatively analogous to that stated in Chapter 4, i.e. to contribute to the empirical findings regarding the interactions between ICT and travel behaviour, while the study's specific aims are to reveal the temporal dynamics and generational differences in such interactions from a (pseudo-)longitudinal perspective. More precisely, this study will answer three research questions which were set to resolve **Objective B**:

a) Have the relationships between Internet use and activity-travel time use for

   non-mandatory (maintenance and leisure) purposes changed during the period between

   2005/06 and 2015? If so, how have these relationships changed over time?

b) Are there any differences in terms of their ICT-travel relationships between

   millennials and the general population? If so, how is millennials' travel behaviour

   differently affected by the use of ICT?

c) Have the ICT-travel relationships evolved differently for millennials during the period

   of study? If so, how have millennials differently changed their behavioural responses to

   ICT use over time?

5.2 Data Preprocessing and Preliminary Descriptive Analysis

In contrast with most longitudinal or repeated cross-sectional (RCS) analyses which rely

on one database, this study utilises datasets from two major household surveys

implemented in Scotland: the 2005/06 Scottish Household Survey (SHS) and the

Integrated Multimedia City Data (iMCD) Survey. The primary reason for adopting two

survey databases, instead of relying on the SHS alone with selection of its two

cross-section waves, is because the key information for this study - the amount of time

adults spent on the Internet - was no longer collected as part of the SHS after 2006. As

outlined in Chapter 3, targeting eight local authority areas of Glasgow and Clyde Valley

(GCV) in Scotland, the iMCD Survey used the same methodology developed by the SHS

in terms of sampling, survey structuring, data collection and weighting. Besides, it

surveyed individuals' time use on the Internet in 2015 by re-adopting the question that was

removed in the later SHS waves. In order to further examine the comparability of the two

Table 5-1 Comparison of demographics of respondents between iMCD survey and 2015 SHS (GCV samples)

	iMCD (2015)		2015 SHS (GCV samples)	
	Mean	S.D.	Mean	S.D.
Age	49.42	18.91	50.93	18.42
16-24	11.55%		10.10%	
25-34	14.42%		14.11%	
35-44	15.89%		15.17%	
45-59	25.87%		26.56%	
60-74	21.62%		22.34%	
75+	10.65%		11.72%	
Gender				
Male	45.68%		44.76%	
Female	54.32%		55.24%	
Employment status				
Self employed	5.12%		4.17%	
Employed full time	32.68%		34.18%	
Employed part time	8.66%		10.85%	
Looking after the home/family	5.07%		4.97%	
Permanently retired from work	28.09%		29.64%	
Unemployed and seeking work	7.03%		3.94%	
At school	1.10%		0.76%	
In further/higher education	5.64%		3.37%	
Government work/training scheme	0.00%		0.01%	
Permanently sick or disabled	3.49%		6.35%	
Unable to work due to short-term illness	1.72%		1.16%	
Other	1.40%		0.60%	
Household size	2.23	1.26	2.13	1.18
Number of kids in household	0.43	0.85	0.40	0.79
Number of cars in household				
0	33.33%		36.50%	
1	42.24%		40.53%	
2	19.31%		18.97%	
3 and plus	5.12%		4.00%	
Living in urban areas	94.13%		96.41%	
Sample size	2,095		2,756	

surveys, the socio-demographics of respondents from the iMCD Survey and the 2015 SHS

for the same local authorities covering GCV are summarised and compared in Table 5-1.

The statistics appear to show that the main demographic characteristics revealed by the two

surveys are quite analogous, which implies that either survey sample could be a good

representative of the population within the authority areas in 2015. In other words, the

iMCD Survey could be treated as the continuation of the early SHS (pre-2007), which

contained information about people's time use on the Internet, targeting the GCV region.

Investigation of the temporal changes in the ICT-travel relationships over ten years is

therefore achievable by using the data from the 2005/06 SHS (the GCV sample) and the

iMCD Survey. A total of 2,095 individual interviews were conducted in the iMCD Survey,

while the GCV sample size of the 2005/06 SHS is 8,436.

5.2.1 Data screening and variable generating by method repetition

5.2.1.1 Key variables: activity-travel behaviour and Internet use

Since the iMCD Survey used the SHS Travel Diary to collect individuals' activity-travel

information, the two surveys' travel datasets were similarly structured. Hence, the same

method of data processing applied in Chapter 4 (see Section 4.2.1.1) was repeated in

dealing with the iMCD travel diary dataset to generate a set of activity-travel variables.

The resulting activity-travel time use for maintenance or leisure purposes was treated as

the dependent variable, whereas that for mandatory purposes was assumed to be one of the

explanatory variables. After removing the cases with missing or invalid information, the size of the adult sample was reduced to 1,484 for the iMCD data, and 5,006 for the 2005/06 SHS-GCV data. In terms of the variable measuring people's Internet usage in 2015, the exact amount of time they spent on the Internet per week for personal purposes is indicated in the iMCD Survey data. In order to unify the measurement in analysis, classification according to the 2005/06 SHS was applied to generate a categorical variable with six Internet-usage categories (i.e. never use, up to 1 hour, from 1 hour up to 5 hours, from 5 hours up to 10 hours, from 10 hours up to 20 hours, and over 20 hours), for the iMCD data.

5.2.1.2 Socio-demographics

In terms of the other predictors whose effects on activity-travel behaviour need to be controlled in modelling, the seven socio-demographic and locational variables (age, gender, number of children and cars in household, availability of valid driving licence, annual income, and residential location), which were included in the models formed in Chapter 4, were also considered in this study. Notably, the income variable modelled in this study is annual personal income rather than household income, as the iMCD dataset does not indicate household income information. Instead of applying the income classification, the amount of personal income was directly modelled as a continuous variable. Since this study attempts to model the temporal changes in terms of relationships (i.e. difference-in-differences), inflation effects, which simply lead to the growth of nominal income over years, need to be eliminated for a better comparison of real income levels in

the two periods. Therefore, the 2015 income values were deflated to 2005/06 British Pound values based on the deflation factor (1.307), which was calculated by using the UK Consumer Prices Index published on the website of the Office for National Statistics (ONS). In addition to the seven factors mentioned above, employment status is controlled as well.

5.2.1.3 Sub-sample: millennial generation

As millennials' behavioural responses to ICT adoption are a particular focus of this study, their samples from both surveys need to be identified and extracted, which is normally performed according to the individuals' birth year. As shown in the literature chapter (Chapter 2), definitions of the exact starting birth year for millennials vary in different cohort studies (ranging from 1976 to 1983), but 1980 is generally seen as the starting point of this generation. As for the ending birth year, it normally varies between the mid-1990s to the early 2000s, with no consensus being achieved in existing studies in this respect either. Based on these definitions, this study tentatively identified the millennial generation according to the range of birth year from 1980 to 2000. According to this identification, there are 408 millennial adult cases in the iMCD sample, and 495 in the 2005/06 SHS-GCV sample. The two millennial samples may show difference in terms of age composition. While the 2005/06 SHS sample mostly includes young millennials with a comparatively narrow age range, older millennials are seen in the 2015 iMCD sample, which is embodied in the descriptive statistics shown below.

5.2.2 Preliminary descriptive analysis

Table 5-2 summarises all the independent variables modelled in this pseudo-longitudinal study, and presents the descriptive statistics of each variable for both full and millennial samples surveyed in 2005/06 and 2015. As shown in the table, the average age of full adult samples in the two surveys is quite similar, approximating to 48, whilst for the millennials, that average increases moderately from 21 in 2005/06 to 25 in 2015, which results from the inclusion of older millennials in the 2015 survey sample. In both survey periods, females make up a slightly greater proportion than males, accounting for 54-56% of the total sample, and this proportion remains almost the same for millennial samples. While the average number of children in a family slightly decreases, from 0.52 in 2005/06 to 0.47 in 2015, ownership of vehicles by a household shows a mild increase during this period, from 0.98 to 1.09 vehicles per household on average. In terms of driver licence ownership, millennial groups generally have a lower rate of licensure compared to the full adult samples in both survey stages. Moreover, this ownership ratio among millennials shows a downward trend over time, decreasing from 60% in 2005/06 to 50% in 2015. After discounting nominal income values in 2015, the average annual personal income over the previous decade witnesses a moderate decrease, possibly owing to the economic recession. Compared to the full sample, the millennial group generally has a lower income in both periods. While, in general, the employment rate experiences a decrease over the ten-year period, for young people, that rate grows from 44% to 58%. Since older cases are included in the 2015 millennial sample, a higher employment ratio would be expected among young

Table 5-2 Descriptive statistics for full and millennial samples over time

	2005/06 (SHS-GCV)						2015 (iMCD)					
	Full Adult Sample			Millennials			Full Adult Sample			Millennials		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
Socio-demographics												
Age	47.54	16.00	94.00	21.12	16.00	26.00	48.65	16.00	92.00	25.30	16.00	35.00
Gender (female =1)	.56	.00	1.00	.57	.00	1.00	.54	.00	1.00	.55	.00	1.00
No. of kids	.52	.00	6.00	.54	.00	4.00	.47	.00	5.00	.50	.00	5.00
No. of vehicles	.98	.00	6.00	.94	.00	4.00	1.13	.00	5.00	.93	.00	4.00
Driving licence (own=1)	.70	.00	1.00	.60	.00	1.00	.68	.00	1.00	.50	.00	1.00
Personal income	13.24	.00	141.37	11.65	.00	38.48	11.85	.00	112.18	9.82	.00	43.26
(thousands of Pounds)												
Employment (employed=1)	.58	.00	1.00	.44	.00	1.00	.52	.00	1.00	.58	.00	1.00
Residential locations												
Urban (reference)	.88	.00	1.00	.92	.00	1.00	.86	.00	1.00	.90	.00	1.00
Town	.06	.00	1.00	.04	.00	1.00	.08	.00	1.00	.08	.00	1.00
Rural	.06	.00	1.00	.04	.00	1.00	.06	.00	1.00	.02	.00	1.00
Internet use												
Never (reference)	.46	.00	1.00	.24	.00	1.00	.17	.00	1.00	.02	.00	1.00
Up to 1 hour	.15	.00	1.00	.14	.00	1.00	.03	.00	1.00	.01	.00	1.00
1 up to 5 hours	.23	.00	1.00	.30	.00	1.00	.11	.00	1.00	.03	.00	1.00
5 up to 10 hours	.09	.00	1.00	.15	.00	1.00	.24	.00	1.00	.21	.00	1.00
10 up to 20 hours	.04	.00	1.00	.10	.00	1.00	.24	.00	1.00	.28	.00	1.00
Over 20 hours	.03	.00	1.00	.07	.00	1.00	.21	.00	1.00	.45	.00	1.00
Sample size	5,006			495			1,484			408		

people as they are more likely to have left schools or university than in 2005/06. As for the residential locations, the rate of city dwellers generally shows a mild decrease over time, and millennials are more inclined to live in cities in both periods.

In terms of time use on the Internet, which is the focus of this study, it is manifest that people generally spend much more time on the Internet for personal purposes at the end of the ten-year period, though 17% still do not use the Internet for those purposes in 2015, compared with 46% in 2005/06. Another substantial change can be seen in the structure of users. In 2005/06, most users only spend no more than 5 hours online per week (i.e. "light users"), whilst by 2015, the majority have turned into "medium-to-heavy users", dedicating over 5 hours to the Internet for personal purposes. Millennials, regarded as "digital natives", show greater dependence on the Internet in both survey periods. In 2005/06, only 24% millennials never use the Internet for personal purposes, with the rate almost doubling for the full adult sample. Although in 2005/06, most millennial users are "light users" as well, 17% of millennials spend over 10 hours a week online (i.e. "heavy users"), compared with only 7% for the whole sample. In 2015, the proportion of non-users among millennials is negligible (2%), and among the users, almost all of them are "medium-to-heavy users". In fact, in 2015, as many as 45% of millennials spend over 20 hours on the Internet every week - this figure is more than double that for the total adult sample.

As suggested in Chapter 3, two modelling approaches are adopted and integrated in this study. First, the two-part model (2PM) is once again applied to deal with the existence of a

large fraction of zeroes in the dependent variables (i.e. activity-travel time use for maintenance and leisure purposes). Second, in order to investigate the temporal changes in the relationships between Internet use and activity-travel behaviour, the difference-in-differences (DD) estimation is employed, based on the pooled cross-section data from the SHS and the iMCD Survey. Specification of the 2PM and the DD method can be found in Sections 3.2.1 and 3.2.2, respectively. This integrated modelling strategy is firstly performed for the full adult sample to answer research question *a)*, and then for the millennial sample to address questions *b)* and *c)*.

5.3 Analysis Results and Discussion

This section details the key results and findings of modelling analysis. It then discusses the implications for planning and policy-making based on these research findings. According to the research questions structuring this study, this section consists of three subsections of result analysis. The first subsection (5.3.1) mainly discusses the temporal changes in the relationships between Internet use and mobility behaviour, according to the results of the 2PM implemented in the RCS (repeated cross sections) context. The distinct ICT-travel relationships for millennials are subsequently discussed in the two subsections that follow, where Section 5.3.2 reveals the differences in terms of the behavioural responses to Internet use between millennials and the general population, and Section 5.3.3 further illustrates how such behavioural responses evolve differently for millennials during the sample period. Final conclusions are then drawn by summarising the findings uncovered in

the three subsections.

5.3.1 Changes in the ICT-travel relationships between 2005/06 and 2015

As Section 5.3 suggests, the two-part model (2PM) is initially run for each survey wave, i.e. the 2005/06 SHS and the 2015 iMCD Survey, to ascertain via result comparison the overall trends of the change for the general adult population in the GCV region. The 2PM results for the two survey waves are summarised and displayed in Table 5-3. As opposed to the presentation of results in Chapter 4, which details the outputs of each modelling stage (i.e. the probit model and the OLS regression model), for simplification purposes, Table 5-3 only displays the average marginal effects (AMEs) of each predictor on activity-travel variables. Results for the 2005/06 SHS in terms of the full Scottish sample (previously discussed in Chapter 4) are also listed as a reference for comparison. By comparing the 2005/06 (GCV sample) and 2015 results, overall stability or variation in terms of the relationships between mobility behaviour and a set of predictors across time can be suggested. It seems that the correlations between socio-demographics and activity-travel behaviour for either purpose remain relatively stable over the ten-year period, which is generally consistent with the full-population results revealed in the analysis of Chapter 4. As for the effect of employment status, which was not directly considered in the 2PM formed in the last chapter, compared to unemployed people, the employed in both survey periods tend to spend less time on both maintenance- and leisure-related activities and

Table 5-3 Results (AMEs) of 2PM for each survey wave: full adult sample

Samples (full adults)	Reference: 2005/06 SHS (full Scotland)				2005/06 SHS-GCV				iMCD 2015			
	Maintenance		Leisure		Maintenance		Leisure		Maintenance		Leisure	
	Activity Duration	Travel Time	Activity Duration	Travel Time	Activity Duration	Travel Time	Activity Duration	Travel Time	Activity Duration	Travel Time	Activity Duration	Travel Time
Socio-demographics												
Age	.150**	-.035**	-.307**	-.048**	.162**	.018	-.298**	-.112**	.052**	.043	-.386*	.066
Gender: female	14.537**	2.247**	.258	-2.077**	15.064**	2.593**	-2.012	-3.713**	19.034**	3.590**	2.043	-1.924
No.kids	2.676**	.536**	-7.486**	-3.043**	1.865**	1.896**	-9.338**	-3.666**	1.813**	1.547**	-9.423**	-2.074**
No.cars	-1.757**	-.602*	1.301**	.815	-2.218*	-.403**	1.591**	1.778*	-5.860**	-.861*	10.161**	2.828**
Owning licence	3.985**	-2.013**	-.836	2.214**	3.086**	-2.221*	1.117	1.879**	6.415*	-3.634**	-2.291	.699*
Personal income	1.071**	.640**	1.236**	.847**	1.822**	.986**	2.346**	1.054*	2.032**	.463**	1.909**	.586**
Employment: employed	-6.824**	-4.059**	-8.785**	-5.036**	-7.216**	-4.366**	-9.312**	-5.867**	-9.144**	-3.187**	-11.025**	-6.076**
Duration_sub	-.193**	-.084**	-.147**	-.060**	-.204**	-.094**	-.149**	-.061**	-.184**	-.038**	-.201**	-.045**
Residential locations (reference: Urban)												
Town	-8.387**	1.581*	-3.430	.628	-4.906**	-.827	3.474	2.729	-7.216*	5.779**	-4.127	-6.778**
Rural	-11.616**	4.156**	-7.681	1.654**	-10.127**	7.411**	-2.919*	-.474	-13.733**	9.164**	-1.870	-.316
Internet use (reference: Never)												
Up to 1hr.	5.114**	2.201	3.645	2.386	5.671*	1.709	3.079	2.846	3.158	.869	6.150	3.106*
1-5 hrs.	8.275**	4.284**	3.367	4.411*	10.223**	3.919**	2.544	4.124*	11.024**	5.567**	2.267	.655
5-10 hrs.	11.448**	4.479**	2.890	1.226	12.814**	4.478**	6.025*	5.066	5.513**	2.029*	4.104	1.893
10-20 hrs.	6.582**	4.066**	3.002	3.354	9.746**	4.122**	1.251	1.383	-8.816**	-4.378**	-7.273**	-4.312**
Over 20 hrs.	2.043	-.991	-1.457	2.036	-2.021	-1.031	-2.487	.198	-14.425**	-7.119**	-10.056**	-6.477**
Observations	15,190	15,190	15,190	15,190	5,006	5,006	5,006	5,006	1,484	1,484	1,484	1,484
Pseudo R^2 (probit model)	.168	.159	.112	.111	.178	.163	.114	.112	.200	.202	.152	.155
R^2 (OLS model)	.118	.116	.071	.060	.119	.117	.091	.080	.121	.119	.114	.114
RMSE (OLS model)	1.122	1.107	1.047	.951	1.137	1.112	1.065	1.048	1.170	1.166	1.124	1.125

*Notes: * Statistically significant at the 10% level.*

*** Significant at the 5% level.*

travels.

In terms of the relationships between Internet use and activity-travel time use, temporal variations can be found according to the modelling results presented. As Table 5-3 shows, in 2005/06, compared with those never using the Internet for personal purposes, Internet users (in the GCV region) generally spend more time on activity participation and trip making for maintenance purposes. This complementary effect caused by Internet use peaks at the 5-to-10-hours usage level and disappears when over 20 hours are spent online, which is quite similar to the results based on the full Scottish sample. In 2015, use of the Internet is still positively correlated to individuals' maintenance-related mobility behaviour if they spend no more than 10 hours online per week. However, for the heavy users, dedicating over 10 hours to the Internet, a negative correlation is found between Internet use and their activity-travel time use. This significant ICT-travel interaction found in 2015, which is due to substitution, is also detected for heavy users in terms of their leisure-oriented mobility, though no significant interaction is revealed for those spending at most 10 hours on the Internet. By contrast, in 2005/06, it is evident from the results table that use of the Internet has no significant effect on people's activity-travel behaviour for leisure purposes, regardless of the amount of time they spend online. In summary, the ICT-travel relationships in terms of non-mandatory activity purposes evolve over time, and this temporal evolution, which is from complementarity (maintenance purposes) or neutrality (leisure purposes) to substitution, takes place significantly among the heavy Internet users, who spend more than 10 hours online every week.

In order to verify the results of the above trend analysis, and to further quantify the changes in the Internet-induced effects, the difference-in-differences (DD) approach is then applied to form a pooled sample and specify the regression model as Eq. 5-2. Table 5-4

Table 5-4 Results (AMEs) of 2PM with inclusion of the DD (difference-in-differences) estimator: full adult sample

Pooled Samples (full adults)	2005/06 SHS-GCV & 2015 iMCD			
	Maintenance		Leisure	
	Activity Duration	Travel Time	Activity Duration	Travel Time
Wave (Wave 2005/06=0)	2.446	-4.645**	-7.086**	-5.127**
Internet use				
(reference: Never)				
Up to 1hr.	5.320	1.412	4.648	2.305
1-5 hrs.	11.536**	4.647**	2.319	1.114
5-10 hrs.	11.829**	4.183**	5.072	3.670
10-20 hrs.	8.844**	3.561**	-3.365	-1.262*
Over 20 hrs.	-1.196	-.204*	.146	.087
*Wave*Internet use*				
(reference: Never)				
Year*Up to 1 hr.	-1.085	.096	2.842	.625
Year*1-5 hrs.	1.123	1.047	-.635	-2.790
Year*5-10 hrs.	-7.241**	-3.068**	-2.210	-3.043
Year*10-20 hrs.	-17.053**	-9.405**	-8.558**	-5.846**
Year*Over 20 hrs.	-15.769**	-7.347**	-10.171**	-7.253**
Observations	6,490	6,490	6,490	6,490
Pseudo R^2 (probit model)	.200	.202	.146	.147
R^2 (OLS model)	.126	.127	.105	.105
RMSE (OLS model)	1.182	1.188	1.067	1.070

Notes: * Statistically significant at the 10% level.

　　　** Significant at the 5% level.

presents the 2PM results. So as to focus on the ICT-travel relationships and simplify the presentation of results, only the average marginal effects (AMEs) of key predictors (Internet use, survey wave indicator) and their interaction items are shown in this results table. According to the results, the wave indicator, where Wave 1 (2005/06 sample) is treated as the reference, generally has negative correlations with individuals' activity-travel time use, especially for leisure purposes. It suggests that people tend to travel less for maintenance purposes and are less likely to undertake outdoor leisure activities over time. The coefficients in terms of Internet use displayed in the table reflect the ICT-travel relationships in the referenced wave (2005/06). Similar to the findings for the 2005/06 sample alone, use of the Internet is, in general, positively correlated with individuals' activity-travel time use for maintenance purposes, but has no significant correlation with their leisure-related mobility. As for the key interest of this study, the temporal changes in the effects of Internet usage are captured by the coefficients of Wave-Internet interaction items, namely, the DD estimators. It is clear that the interaction items are significantly and negatively correlated with individuals' maintenance-related mobility only for those Internet users spending over 5 hours online per week. Since the complementary effects of Internet use have been generally detected for those users in 2005/06, the negativity of coefficients implies that at the same usage levels, use of the Internet in 2015 tends to generate less or even substitute physical activity undertaking and trip making for maintenance purposes. In fact, the substitution relationship is found among heavy users, with over-10-hours usage in 2015, when the changes are added to the Internet-induced effects in 2005/06. This result is consistent with the findings of the trend analysis above. However, for the light Internet users, who spend no more than 5 hours online, the DD estimators are not significantly

correlated with the activity-travel variables, which means the ICT-travel relationships in terms of maintenance purposes do not change significantly among light users over the ten-year period. Likewise, temporal changes in the interaction between Internet use and mobility behaviour for leisure purposes are only found to be significant for the heavy Internet users, and the changes are negative as well. As the effects of Internet use on leisure-related mobility are neutral in 2005/06, they may become negative for the heavy users in 2015 after adding the changes, which is in line with the results of trend analysis.

To sum up, the Internet-travel relationships, in terms of both maintenance and leisure activity purposes, change over time, and such changes are generally negative, resulting in less generation or even substitution effects on mobility. However, the temporal changes are significant only for the medium-to-heavy Internet users who spend over 5 hours online and, as a result, form a new ICT-travel interaction of substitution instead of complementarity or neutrality for those heavy users. It seems that the technological evolution over time tends to transform the role of ICT from being that of a facilitator into being that of a discourager, in terms of influencing people's engagement in physical activities and travel, especially for those showing high reliance on technologies in daily life. This would not be surprising since the increasing application of ICT in all aspects of life, such as teleshopping, telemedicine and e-banking, enables and stimulates people to replace physical activities with virtual ones, particularly for those dedicating a large share of their daily time budget to the Internet.

5.3.2 Distinct ICT-travel relationships among millennials

Before moving on to explore the temporal dynamics in the ICT-travel interactions for millennials, their behavioural responses to adopting ICT, in terms of activity performing and trip making, are firstly captured and compared to those of the general adult population. Clearly, the modelling strategy of market segmentation, which has been previously adopted in Chapter 4, is still employed to investigate a set of activity- or travel-related relationships among different generational groups. Prior to running models for the targeted group (millennials), the choice of such strategy in this research context was statistically validated by applying the methods and procedures (i.e. the likelihood ratio test) that are same to those previously used in Chapter 4 (see Section 4.3.3).

Similar to the trend analysis undertaken for the full adult samples, the two-part model (2PM) is individually run for the millennial sample of each survey wave (2005/06 and 2015) and the results are summarised in Table 5-5. By comparing the results of Table 5-5 with those shown in Table 5-3, many differences in terms of the relationships between predictors and mobility behaviour can be found between the millennial and the general adult groups. For instance, the correlation between age and activity-travel time use is only found to be significant for the full adult samples, where older people tend to spend more time on maintenance activities, but less time on leisure ones. Millennials' participation in non-mandatory activities seems not to be influenced by age. Likewise, the effects caused by gender and the number of children in a household also vary between the two adult

Table 5-5 Results (AMEs) of 2PM for each survey wave: millennial sample

Samples (millennials)	2005/06 SHS-GCV				iMCD 2015			
	Maintenance		Leisure		Maintenance		Leisure	
	Activity Duration	Travel Time	Activity Duration	Travel Time	Activity Duration	Travel Time	Activity Duration	Travel Time
Socio-demographics								
Age	.081	-.297	-1.048	.059	.044	.331	-.450*	-.077
Gender: female	3.879	-1.250*	-2.019	.752	5.115*	.084	-1.076	-3.134
No.kids	.356	-.127	2.071	.064	1.650**	1.038**	-4.762*	-.619**
No.cars	-4.160**	-1.307**	3.468**	2.617**	-2.118**	-1.361	7.082**	3.405*
Owning licence	2.465**	-2.150**	5.464**	3.421*	4.706*	-1.879**	3.753**	.689**
Personal income	1.540**	.479*	6.706**	4.547**	2.160**	.337**	3.442**	1.087*
Employment: employed	-4.407**	-2.116**	-7.994**	-5.323**	-7.569**	-3.052**	-12.481**	-7.677**
Duration_sub	-.189**	-.091**	-.154**	-.063**	-.196**	-.041**	-.204**	-.050**
Residential locations (reference: Urban)								
Town	-.569	1.291*	2.076	-.717*	-4.569**	3.704**	.892	1.603
Rural	-6.071**	4.480**	1.562	-.481	-8.321**	5.546**	-2.150	-1.441*
Internet use (reference: Never)								
Up to 1hr.	2.004	-.547	1.165	.094	-.681	-.760	-.472	-1.530*
1-5 hrs.	.876	.318	-3.741	-.760*	-6.452**	-3.507**	-5.416**	-2.227**
5-10 hrs.	-6.160**	-2.694**	-7.063**	-3.115**	-5.606*	-3.163**	-8.814**	-3.606**
10-20 hrs.	-9.775**	-4.362**	-11.240**	-4.427**	-10.479**	-5.241**	-10.755**	-4.725**
Over 20 hrs.	-11.218**	-4.830**	-12.582**	-4.881**	-13.153**	-5.819**	-13.130**	-6.046**
Observations	495	495	495	495	408	408	408	408
Pseudo R^2 (probit model)	.180	.167	.166	.163	.202	.200	.171	.169
R^2 (OLS model)	.117	.115	.116	.115	.123	.119	.118	.118
RMSE (OLS model)	1.133	1.119	1.130	1.127	1.177	1.166	1.160	1.158

*Notes: * Statistically significant at the 10% level; ** Significant at the 5% level*

groups. In the general adult group, females tend to spend more time undertaking maintenance tasks and associated trips than males do, whereas for milllennials, the traditional gender division in undertaking these tasks is no longer found to be significant. The insensitivity of millennials' activity-travel behaviour to the number of children in a family is also detected, but only in 2005/06. In 2015, the number of children is positively correlated with millennials' maintenance-related mobility, but negatively correlated with their time use on leisure-related mobility, which is similarly revealed for the full adult samples in both survey waves. This temporal change in the correlation is probably because the 2015 millennial sample contains older individuals, who are more likely to have their own kids instead of being the "big kids" in their families.

The relationships between Internet use and activity-travel time use for the two adult groups also significantly differ. As revealed previously, for the general population, the ICT-induced effects in 2005/06 are complementarity and neutrality in terms of maintenance and leisure purposes, respectively, and evolve to substitution for the heavy Internet users in 2015. For millennials, however, the Internet users generally spend less time on activity participation and trip making for both maintenance and leisure purposes in both survey periods, suggesting a substitution relationship between ICT and travel behaviour even at the earlier point. Moreover, the more time these young users dedicate to the Internet, the less time they spend undertaking physical activities and trips, except for those only spending at most 1 hour online per week. Clearly, millennials tend to substitute physical non-mandatory activities with virtual activities online, while the general population are likely to utilise the Internet to facilitate their physical mobility for

maintenance purposes, especially at the earlier point. Arguably, as digital natives, millennials' heavy dependence on ICT in their daily lives to a large extent makes them become the "go-nowhere" generation (Buchholz & Buchholz, 2012; McDonald, 2015).

5.3.3 Temporal changes in the ICT-travel relationships among millennials

In addition to highlighting millennials' behavioural responses to use of ICT, Table 5-5 also reveals the evolution in such responses over time. It seems that the way ICT interacts with millennials' mobility behaviour generally remains stable over the ten years, which is substitution in terms of both maintenance and leisure purposes. Nevertheless, variations in the ICT-travel interactions can still be found if attention is paid to the levels of Internet usage. It is clear from Table 5-5 that in 2005/06, the substitutive effects of Internet use on activity-travel behaviour are only found to be significant in terms of both activity purposes for those spending over 5 hours online (i.e. the medium-to-heavy users). In 2015, however, while the significant effects remain for the medium-to-heavy usage, they are also now seen for the light Internet users. In other words, for millennials, the temporal changes in the ICT-travel relationships seem to be more significant for the light Internet users, where an evolution from neutrality to substitution in terms of interaction is seen.

Similar to the analytical process adopted for the full adult samples, the 2005/06 and the 2015 millennial data are then pooled to perform the DD estimation. The 2PM results

relating to the key predictors (survey wave indicator, Internet use, and their interaction items) are displayed in Table 5-6. Similar to the results derived from the full-sample models, the wave indicator, in general, is negatively correlated with millennials' activity-travel time use for both activity purposes, suggesting that millennials are more

Table 5-6 Results (AMEs) of 2PM with inclusion of the DD (difference-in-differences) estimator: millennial sample

Pooled Samples (millennials)	2005/06 SHS-GCV & 2015 iMCD			
	Maintenance		Leisure	
	Activity Duration	Travel Time	Activity Duration	Travel Time
Wave (Wave 2005/06=0)	-6.190**	-4.827**	-9.705*	-6.861**
Internet use				
(reference: Never)				
Up to 1hr.	1.764	-.187	.886	-.036
1-5 hrs.	-.360	.109	-3.832	-.874*
5-10 hrs.	-5.942**	-2.737**	-7.527**	-3.108**
10-20 hrs.	-10.137**	-4.866**	-11.036**	-4.540**
Over 20 hrs.	-12.026**	-5.152**	-12.814**	-5.007**
*Wave*Internet use*				
(reference: Never)				
Year*Up to 1 hr.	-1.813*	-.558**	-1.465**	-1.620**
Year*1-5 hrs.	-7.220**	-3.671**	-6.835**	-2.044**
Year*5-10 hrs.	.346	-.405*	-1.216**	-.507*
Year*10-20 hrs.	-.407	-.413	.335	-.176
Year*Over 20 hrs.	-.951	-.682	-.327	-.853
Observations	903	903	903	903
Pseudo R^2 (probit model)	.167	.167	.170	.168
R^2 (OLS model)	.116	.115	.116	.114
RMSE (OLS model)	1.122	1.120	1.123	1.120

Notes: * Statistically significant at the 10% level.

    ** Significant at the 5% level.

likely to "go nowhere" over time. As previously revealed, the relationships between Internet use and millennials' mobility behaviour in the referenced wave (2005/06) are due to neutrality for the light Internet users, and to substitution for other users. The changes in such relationships over time are reflected by the effects of the Wave-Internet interaction items (i.e. the DD estimators), which differ according to the Internet usage level. It is manifest that within the 10 hours' usage, the interaction items are significantly and negatively associated with activity-travel variables, implying that in the later survey wave (2015), at the same usage level, using the Internet tends to substitute more for physical non-mandatory activity performing and trip making for millennials compared with the referenced wave. These negative changes in the ICT-travel relationships peak at the 1-to-5-hour usage. Nevertheless, for the heavy users, who spend more than 10 hours online, there are no significant changes in the Internet-induced effects over time, as the difference-in-differences (DD) estimators are generally not significantly correlated with mobility behaviour for either purpose. Once again, these results support the findings of trend analysis, suggesting that the temporal changes in the relationships between Internet use and activity-travel behaviour for millennials are only significant among the light or medium-to-light Internet users, and such changes are negative.

Comparing the results with those previously revealed for the general adult population, a similar finding is that for both adult groups, the temporal changes in the ICT-travel interactions over the ten-year period are negative if changes are found to be significant. This implies that, in general, the complementary effects of Internet use on individuals' non-mandatory mobility are diminishing over time, whereas its substitutive effects are

increasing. Meanwhile, the dissimilarity in findings also stands out. For general adults, the changes are only significant among the medium-to-heavy Internet users, who spend over 5 hours online, whilst for young adults, it is the light users (spending no more than 5 hours) or medium-to-light users who see the significant changes. It seems that regardless of the increasing opportunities for substituting mobility brought about by technological evolutions over time, further reduction in travel may not be significantly achieved any more for the young heavy users, who have already greatly substituted their physical activities and travels with online activity performing at an early point, suggesting that adoption of or even reliance on ICT in daily life is still unlikely to completely replace physical mobility at this stage.

5.4 Summary and Policy Implications

5.4.1 Conclusion of analyses

Extending the scope of Chapter 4, this study investigates the temporal dynamics in the relationships between Internet use and activity-travel behaviour in terms of non-mandatory activity purposes, particularly for the millennial generation, whose mobility patterns and ICT usage patterns both exhibit uniqueness. In order to achieve a (quasi-)longitudinal analysis, this study overcomes data and information deficiency by using datasets from two major cross-sectional surveys implemented in Scotland, i.e. the 2005/06 Scottish

Household Survey (SHS) and the Integrated Multimedia City Data (iMCD) Survey, which are similarly structured and formed. The two-part model (2PM) is applied to examine the overall trends of changes in the ICT-travel relationships over time, and then specified by the DD (difference-in-differences) approach to capture the exact temporal changes, for both general adult population and millennials. Results of the analysis have been discussed in detail above, and from this, the main conclusions can be drawn by answering the three research questions introduced at the start of the chapter:

a) Have the relationships between Internet use and activity-travel time use for

   non-mandatory (maintenance and leisure) purposes changed during the period

   between 2005/06 and 2015? If so, how have such relationships changed over time?

Over the survey period, changes are found in the ICT-travel relationships in terms of non-mandatory activity purposes, and these changes are generally negative. More specifically, they tend to breed a new relationship of substitution, rather than the complementarity (for maintenance purposes) or neutrality (for leisure purposes) relationships that are found at the earlier point (2005/06). It suggests that ICT are more likely to play a discouraging rather than a facilitating role in affecting their users' activity performing and trip making as a result of technological evolution over time. However, such changes are only significantly detected for the medium-to-heavy Internet users, spending over 5 hours online per week. Since technological evolution creates increasing opportunities for tele-activities performing, those heavy users, who already dedicate a large amount of time to the Internet, are more likely to make use of the opportunities to

substitute their physical pursuits in order to balance their time use budgets.

b) Are there any differences in terms of the ICT-travel relationships between millennials and the general population? If so, how is millennials' travel behaviour differently affected by the use of ICT?

The ICT-travel interactions among millennials significantly differ from those found for the general adult population. For millennials, the amount of time spent on the Internet is negatively correlated with their activity-travel time use for both maintenance and leisure purposes, even at the earlier point. By contrast, for general adults, the substitutive interactions between Internet use and mobility behaviour are only seen among the heavy Internet users (more than 10 hours' usage) in 2015, whilst interactions of complementarity and neutrality are generally suggested in 2005/06. As digital natives, millennials tend to substitute rather than complement their physical participation in non-mandatory activities with virtual activities online, turning them into the "go-nowhere" generation to a large extent.

c) Have the ICT-travel relationships evolved differently for millennials during the period of study? If so, how have millennials differently changed their behavioural responses to ICT use over time?

The temporal changes in the ICT-travel relationships are seen to be different for millennials compared with those found for general adults. For millennials, only the light

users (spending no more than 5 hours online ever week) or the medium-to-light users see the significant changes over time, which leads to an evolution from neutrality to substitution in terms of the relationships. As previously suggested, however, such temporal changes for the general adult population are only found to be significant among the heavy or medium-to-heavy Internet users. Although an increase in the opportunities for substituting physical mobility (resulting from technological development) generally encourages the ICT dependants (i.e. heavy ICT users) to reduce their participation in out-of-home activities and travels, it may not lead to further such reductions for the young dependants who have already significantly substituted physical pursuits with virtual ones at a very early point. The findings suggest that at this stage, people's demands for physical travel for non-mandatory activity purposes could be reduced but not eliminated as a result of ICT adoption, or may even suggest ICT dependence.

5.4.2 Policy and planning implications

The research findings recommend that urban or transport policy strategies adopting technological interventions to achieve better efficiency and sustainability should be formed with a long-term perspective, as the effects of such interventions may change over time due to the rapid evolutions in technologies. In addition, the different behavioural responses to ICT adoption between millennials and the general adult population may suggest that planners and policy-makers require more generation-specific travel demand predictions when including ICT-based strategies to effect behavioural changes in the agenda of

sustainable mobility. Moreover, since the ICT-travel relationships are acknowledged and utilised in policy-making, there is a need to link the two policy domains, of ICT promotion and sustainable transport planning in order to enhance overall policy efficiency. The concept of digital citizenship is central to information and digital policy-making as citizenship is increasingly mediated by digital communications. Therefore, alleviating digital exclusion or the digital divide has been prioritised. Since older people tend to be less tech-savvy and find it harder to inhabit a technologically saturated society compared to millennials or "digital natives", age has been highlighted in policy attempts to achieve digital inclusion. The expected policy effects of digital inclusion, together with the rapid technological evolution over time, could create more possibilities for introducing ICT-based interventions in transport policy-making where changes in travel behaviour are ultimately pursued.

Chapter 6 Effects of Past ICT Experience on Attitude Formation and Travel Behaviour: A Longitudinal Perspective

Chapter 5 focused on the varying effects of ICT use on activity-travel behaviour according to generation. Since millennials' transport demands are increasingly highlighted in current transport policy making for achieving a sustainable future (Davis et al., 2012; Garikapati et al., 2016), this chapter will now narrow the focus and make a special effort to investigate the millennial generation's travel patterns and lifestyles as well as the connections to their ICT experience. As suggested before, as "digital natives", who were born and raised in the digital era, millennials' heavy reliance on a variety of Information and Communication Technologies (ICT) in their daily lives has largely reshaped their transport needs and activity-travel patterns (Lyons, 2015). ICT, on the one hand, have the potential to substitute physical travel with virtual activities (teleworking, e-shopping, online socialising, etc.). On the other hand, their application in the transport sector has brought about various technology-enabled transport services and tools, such as real-time information provision, car-sharing apps, and on-board Wi-Fi, which make public transport, cycling, ridesharing, and other modes more attractive to travellers, thereby potentially reducing car use (Dutzik et al., 2013; Dutzik et al., 2014; Martin et al., 2010). Millennials seem to be more susceptible to these ICT-induced effects as they are more tech-savvy than earlier generations (Circella et al., 2016; Dutzik et al., 2014; van Wee, 2015); this has also been

demonstrated by the study in Chapter 5. Together with the dramatic socioeconomic changes that the millennial generation has encountered, such as economic recession, high unemployment, and delayed marriage and transition into adulthood, heavy reliance on ICT contributes to seemingly more sustainable mobility patterns, including driving less, using alternative modes (e.g. public transport, bicycle) more often, and generally travelling less (Dutzik et al., 2014; Garikapati et al., 2016; Thakuriah & Geers, 2013).

In this behavioural transition to a seemingly more sustainable mobility paradigm that is largely fuelled by heavy ICT adoption in daily life, attitudes may play an intermediary but important role. Much research on millennials' mobility patterns and travel choices has considered their environmental attitudes and concerns (Circella et al., 2016; Dutzik et al., 2014; Sakaria & Stehfest, 2013), as millennials are often described as being more committed to sustainability and environmental protection (Circella et al., 2016). These studies generally concluded that their pro-environment attitude correlates with millennials' sustainable travel behaviour (including less car use and more use of other modes of transport) – a conclusion consistent with classical behavioural theories (e.g. the theory of planned behaviour, the value-belief-norm theory), which all highlight the causal link between attitudinal factors and behaviour. Based on the attitude–behaviour relationship, attempts have been made to direct behavioural changes towards more sustainable patterns by influencing attitudes, and ICT was found to be effective in exerting such an influence. For example, the Internet, as an information depot, can increase people's environmental consciousness and awareness through information spreading and knowledge provision (Good, 2006; Nistor, 2010; Stokols & Montero, 2002). In addition, the Internet has a great

potential to enhance environmental activism and governance (Pickerill, 2003; Stokols & Montero, 2002; Zelwietro, 1998). Moreover, according to the emerging theory of *captology* (i.e. the study of computers as persuasive technologies), computers and the Internet can act as persuaders in changing people's attitudes and behaviour (Fogg, 2003), enabling people to convince their peers to be more environmentally friendly online (Allen et al., 2013). The relationships between ICT use and behaviour, and between attitudes and behaviour, have been well studied tor understand millennials. However, the ICT-induced influences on millennials' attitudes, and the intermediary role attitudes play between ICT use and behaviour, have received little attention.

Another important issue, which is often overlooked in research on millennials' mobility and ICT, is the effect of millennials' past ICT experiences and changes in ICT usage over time on their current behaviour. As millennials were born and grew up in the information era, their mobility patterns and lifestyles may be characterised by their long-term ICT experience starting from a young age. Therefore, in order to thoroughly understand the role of ICT in shaping millennials' travel behaviour, it may be necessary to examine from a longitudinal perspective the long-term effects of ICT adoption starting from the early stages of millennials lives. As reviewed in Chapter 2, the theory of hysteresis in behaviour conceptualises the reliance of behaviour on past history, indicating that current preferences are closely related to a past history of behavioural choices (Elster, 1976; Georgescu-Roegen, 1971). However, as longitudinal analysis is normally required, research on such dynamic effects is inadequate, due primarily to the unavailability of data sources. Although a few studies have presented some enlightening findings (e.g. Kim &

Goulias, 2004; Thulin & Vilhelmson, 2006), they have not considered the effects of past ICT experience or changing use of ICT over time on people's attitudes, both of which indirectly shape behaviour. In addition, the period during which the changes took place in these studies is generally short, so they may not fully explain the long-term effects of ICT use on mobility behaviour.

To address the research gaps identified above, this chapter attempts to explore both the direct and indirect effects of Internet use, including past and current Internet usage, on young adults' environmental attitudes and travel choices. Their pro-environmental behaviour is also modelled to get an overall assessment of the sustainability of millennials' lifestyles. This chapter starts by highlighting the objectives and related research questions in Section 6.1. This is followed in Section 6.2 by a description of the data sources adopted, i.e. 2004 British Household Panel Survey (BHPS) and Understanding Society (Wave 4, 2012/13), as well as of the data preprocessing and variable formation. After that, Section 6.3 is devoted to demonstrating the methodology of this chapter, with model specification and statistical power evaluation discussed. The key modelling analysis results are presented and discussed in Section 6.4. Finally, a summary of these findings with possible policy and planning implications is provided in Section 6.5.

6.1 Objective and Research Questions

The overall purpose of this study is to enrich the evidence-based findings regarding

millennials' mobility behaviour and sustainable lifestyles with their connections to ICT adoption. In order to get a deeper insight into how ICT shape millennials' mobility patterns and lifestyles by influencing their attitudes (the focus of **Objective C** of this thesis), longitudinal analysis will be performed, starting from the early stages of millennials' lives, to investigate the long-term effects of Internet use on their current travel choices and pro-environmental behaviour. This analysis will include consideration of the mediating role millennials' attitudes play in the ICT—behaviour relationship. More specifically, the primary question this study attempts to answer is:

How do past Internet usage in adolescence and changes in usage over time directly or indirectly influence young adults' environmental attitudes, travel choices, and pro-environmental behaviour?

In order to obtain more insight into this question, two issues are also considered: *a) the effects of (current) Internet use on young adults' environmental attitudes, travel choices, and pro-environmental behaviour,* and *b) the relationship between environmental attitude, and travel and pro-environmental behaviour*.

6.2 Data Preprocessing and Preliminary Descriptive Analysis

As introduced in Chapter 3, this study is based on datasets from two nationwide longitudinal household surveys: the British Household Panel Survey (BHPS) and

Understanding Society (the UK Household Longitudinal Study) survey. The two surveys have similar structures, shaped by four questionnaires: a *household questionnaire,* investigating household composition and socioeconomic situations; an *individual questionnaire,* a *self-completion questionnaire* to understand the socio-demographic status, behaviour and attitudes (including Internet usage, travel choices, pro-environmental attitudes, and behaviour) of every adult in each household; and a *youth questionnaire,* to understand the behaviour and attitudes of young people (aged 10–15) in households, including their Internet usage. A "predecessor" of Understanding Society, the BHPS became a part of Understanding Society (from Wave 2 onwards) with its sample incorporated into the latter in 2009. To facilitate the linkage between the two survey datasets, each of the BHPS sample members is issued a unique identifier within the Understanding Society datasets. For this research, as longitudinal analysis is designed to investigate the long-term effects of past ICT experience (in adolescence) on young people' attitudes and travel and environmental behaviour, young adults' past usage of the Internet needs to be linked to their current Internet-use habits, attitudes, and behaviour. According to the data features of the BHPS and Understanding Society, the youth sample contained in the youth survey of an early BHPS was firstly tracked in an individual survey dataset of a later Understanding Society survey with the use of the unique identifiers, thereby creating a comprehensive dataset containing information about each young person in both adolescence and adulthood. As they include all the key variables across the relevant time span, the 2004 BHPS and the 2012/13 (Wave 4) Understanding Society survey were selected as the panel data sources for this study. In the 2004 BHPS, 1,397 adolescents aged 11-15 completed the youth questionnaire. After matching with the 2012/13 Understanding

Society dataset via the unique identifiers, the initial youth sample size was reduced to 1,306.

6.2.1 Data screening and variable generation

The comprehensive dataset, which results from the combination of the BHPS and Understanding Society data, includes 1,306 young person records with both a household identifier and a unique person identifier issued to each person. Since two or more individual cases may come from the same household, each household identifier issued may not be unique. Each individual record contains a wide variety of information, among which information on environmental attitude, travel and pro-environmental behaviour, and Internet-use habits in both adolescence and adulthood forms the key variable set in this study. In addition, a set of socio-demographic and built environment factors is also considered as the control variables in the model. Data preprocessing for generating these variables is shown below.

6.2.1.1 Past, current and changing usage of the Internet

In the comprehensive dataset, young people's Internet use was recorded in terms of frequency of accessing the Internet in both adolescence (from the BHPS) and adulthood (from the Understanding Society survey). Respondents indicate their level of Internet usage for personal use by placing themselves into one of the following bands: never use,

less than once a month, at least once a month, at least once a week, and every day. To embody the degrees of the young people's dependence on the Internet, based on their usage frequency, they were further spilt into two groups of *light Internet users* and *heavy Internet users* in their two life stages. A heavy Internet user is defined as a person using the Internet every day, and a person without a daily-use habit is defined as a light Internet user. After removing all the cases with missing information on Internet use and behaviour, the size of the sample was reduced from 1,306 to 792. Table 6-1 summarises young people's Internet-usage profile in their adolescence (2004) and adulthood (2012/13). It is apparent that young people's dependence on the Internet has substantially increased as they grow older. In 2004, only 25.6% of the sampled youths were heavy Internet users; but by

Table 6-1 Young people's Internet-usage habits in adolescence (2004) and adulthood (2012/13)

Frequency of Usage	Level of Usage	Percentage (%)	
		2004	2012/14
Never	Light Internet Users	20.2	0.5
Less than once/month		7.3	0.2
At least once/month		12.2	3.4
At least once/week		34.7	12.5
Every day	Heavy Internet Users	25.6	83.4
Sample size		792	792

2012/13, this figure had increased significantly, to 83.4% of young adults. In the same interval, the proportion of non-users declined dramatically, from 20% in 2004 to almost zero in 2012/13.

Since the interest of this study is the long-term and dynamic effects of Internet experience on behaviour and attitude, changes in Internet usage over time need to be embodied as variable(s). Based on young people's past and current Internet-use habits identified above, indicator variables for four groups of persons were created to reflect such changes:

- *new heavy users*: persons who were light Internet users in 2004 but are now heavy users;

- *past heavy users*: persons who were heavy Internet users in 2004 but are now light users;

- *experienced heavy users*: persons who were heavy Internet users in 2004 and still are;

- *stubborn light users*: persons who were light Internet users in 2004 and still are.

6.2.1.2 Attitudes and behaviour

The young adults' attitudes and behaviour (including their travel choice behaviour and pro-environmental behaviour) are considered as the endogenous variables in the model for study and were recorded as a set of ordinal variables in the dataset. People's travel choice behaviour is represented by the frequencies of traveling by car, bus, train, and bicycle, with five frequency levels provided: less than once a year, at least once a year, at least once a month, at least once a week, and at least once a day. In addition, frequency of travelling by car sharing is measured by another five-point scale: never, not very often, quite often, very often, and always. The same frequency scale is applied to describe young adults'

pro-environmental behaviour in terms of their energy-saving habits (using electricity, water, and heating) and environmentally friendly shopping, from "never" to "always". Notably, water use is represented by frequency of wasting water in daily life, which means that as one moves along the scale from "never" to "always", it implies a decreasingly pro-environmental pattern. In order to model young people's environmental attitudes, six attitudinal variables (see Table 6-3) in the dataset are selected, with an attitude scale used to measure each of them. To measure four of the attitudinal variables relating to attitudes towards "going green", climate change, environmentally friendly product purchasing, and changes for helping environment, a typical Likert scale was employed, indicating the respondents' levels of agreement/disagreement in attitude as: *disagree strongly*, *disagree* (including *tend to disagree* and *neither agree nor disagree*), *tend to agree*, and *agree strongly*. The other two variables measure people's perceptions of environmentally friendly lifestyles according to their current situations.

6.2.1.3 Socio-demographics

In addition to the key variables of Internet usage, behaviour, and attitude, ten socio-demographic variables have also been included in the model. While age, number of kids, adults and vehicles in household, and monthly household income (thousands of British Pounds) are continuous variables, female (gender), living with parents or not, and holding driving licence or not are "yes/no" binary variables. Employment status is measured as a categorical variable with three indictors, i.e. employed, unemployed, and student. Moreover, a simple urban/rural classification (rural area="0"; urban area="1") is

applied to measure people's residential location.

6.2.2 Descriptive statistical analysis

All the exogenous variables considered in this study, including socio-demographics, residential location, and Internet usage (including its change level), are summarised in Table 6-2, which also displays the descriptive statistics for each variable. The statistics reveal that there is a greater amount of females, accounting for over 53% of the total sample. The ages of the sampled young adults range from 18 to 24, with an average of 20 to 21. While the average number of children is generally less than 1 per household, the average number of adults is 3 to 4, and the average vehicle ownership is 1.76 per household. As for household income, its average level is £3,390 per month in 2012/13. Among the sampled young adults, 77% choose to live with their parents, which is not surprising given the low ratio of employment (37%) and that nearly 50% are students. Moreover, half of them hold a valid driving licence, and most (72%) live in urban areas. Table 6-2 also presents the indicator variables of Internet use and changes in use over time. It is clear that most of the young adults (over 60%) behave as new heavy users of the Internet, and less than 3% of them drop the habit of using the Internet daily when they leave adolescence. In addition, almost a quarter of them have been heavy users since they were in their adolescence, and the remaining have never used the Internet on a daily basis (*stubborn light users*).

Table 6-2 Descriptive statistics of socio-demographics and the Internet use of young adults (N=792)

Variable Name	Descriptions	Mean	Min.	Max.
Socio-demographics				
Female	Gender: Male='0', female='1'	53.50%	0	1
age	age	20.47	18	24
kid0_4	Number of kids aged 0-4 in household	.11	0	2
kid5_15	Number of kids aged 5-15 in household	.28	0	4
adults	Number of adults in household	3.29	1	7
vehicles	Number of vehicles in household	1.76	0	3
income	Monthly household income (thousands of British Pounds)	3.39	.27	20.00
parent	Living with parents or not	77.17%	0	1
employed	Employment status: employed	37.34%	0	1
student	Employment status: student	49.59%	0	1
unemployed	Employment status: unemployed	13.07%	0	1
license	Holding driving license or not	50.61%	0	1
urban	Living in: rural area ('0'), urban area ('1')	71.78%	0	1
Internet usage				
interfreq1	Frequency of using the Internet: never use	0.49%	0	1
interfreq2	Use less than once/month	0.16%	0	1
interfreq3	Use at least once/month	3.42%	0	1
interfreq4	Use at least once/week	12.54%	0	1
interfreq5	Use every day (*heavy users*)	83.39%	0	1
Past and changing use of Internet				
stubborn	Stubborn light users	11.85%	0	1
new	New heavy users	61.52%	0	1
expered	Experienced heavy users	24.04%	0	1
past	Past heavy users	2.59%	0	1

Table 6-3 summarises all the behavioural and attitudinal variables which are modelled as the endogenous variables in this study. According to Table 6-3, it is clear that private cars/vans are still the most popular travel mode for young adults, with around 55% of the

Table 6-3 Distributions of behavioral and attitudinal variables used (N=792)

Categories	Variable Name/Description	Frequency or Attitude Scales (% of total sample)				
Travel Choices		*Less than once/year*	*At least once/year*	*At least once/month*	*At least once/week*	*At least once/day*
	car/Frequency of travelling by private car/van	2.2%	2.9%	9.0%	31.0%	54.9%
	bus/Frequency of travelling by bus	27.9%	15.7%	19.6%	23.8%	13.0%
	train/Frequency of travelling by train	25.8%	32.2%	26.5%	10.2%	5.3%
	cycling/Frequency of travelling by bike	62.2%	15.5%	7.9%	9.3%	5.1%
		Never	*Not very often*	*Quite often*	*Very often*	*Always*
	shared/Frequency of travelling by car sharing	52.7%	10.2%	18.2%	11.8%	7.1%
Environmental Behavior	light/Switching off lights	2.5%	7.5%	14.3%	23.9%	51.9%
	water/Keep the tap running while you brush your teeth	39.0%	19.9%	16.8%	13.3%	11.1%
	heating/Put more clothes on when you feel cold rather than relying on heating	12.7%	12.4%	20.0%	28.4%	26.5%
	recycled/Buy recycled paper products	47.0%	22.3%	17.1%	8.1%	5.5%
	bag/Take your own shopping bag when shopping	40.2%	14.1%	12.0%	13.1%	20.5%
	changenvir/Help environment with changes fitting with lifestyle	3.2%	9.1%	26.4%	45.4%	15.9%

(Continued)

sample using them for travel on a daily basis. In contrast, cycling is the least popular mode choice, with over 62% of young persons using it less than once a year. In terms of the use of public transport, the bus is more frequently used in young people's daily travel than the train, with around 37% of the sample using it more than once per week or even every day.

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Table 6-3 Continued

Categories	Variable Name/Description	Frequency or Attitude Scales (% of total sample)				
Attitudes & Perceptions		*Happy with what I do*		*Like to do bit more*	*Like to do lots more*	
	feellife/How feel about current lifestyle and the environment	49.5%		32.3%	18.2%	
		Do nothing env friendly	*1/2 things env friendly*	*Few things env friendly*	*Mostly env friendly*	*Everything env friendly*
	lifeenvir/Current lifestyle environmentally friendly	10.7%	43.6%	31.7%	10.5%	3.5%
		Disagree strongly	*Tend to disagree*	*Neither agree nor disagree*	*Tend to agree*	*Agree strongly*
	beingreen/Being green is an alternative lifestyle for the majority	5.0%	25.8% (*Disagree*)		53.3% (*Agree*)	15.9%
	behavclim/Behavior contributes to climate change	3.3%	8.6%	22.3%	46.7%	19.1%
	envirprod/Pay more for environmentally friendly products	4.1%	8.9%	27.6%	43.2%	16.2%
	changenvir/Help environment with changes fitting with lifestyle	3.2%	9.1%	26.4%	45.4%	15.9%

As for environmental behaviour, the young adults generally do well in their rational use of resources, as most of them consume energy (electricity, water, and gas) conservatively. However, their purchasing behaviour seems to be less environmentally friendly, since almost half never buy recycled paper products or take their own bags when shopping. In terms of attitudes, young people are generally pro-environmental. Over half of them would like to do more to help the environment, though less than 15% of them feel their current lifestyles are environmentally friendly in most or even all aspect. Nearly 70% of people agree that "being green" is an alternative lifestyle for the majority, and 65.8% of them

believe that their behaviour contributes to climate change. In contrast to their current purchasing behaviour, which shows insufficient environmental concern, about 60% of young adults would be prepared to pay more for environmentally friendly products in the future. Additionally, most people (over 60%) would like to help the environment with changes that fit in with their lifestyles.

6.3 Model Specification and Statistical Power Evaluation

As indicated in Chapter 3, the structural equation model (SEM) is employed to examine the complex interactions among multiple factors, including Internet use, environmental attitudes, travel choice, and pro-environmental behaviour. While the structure and estimation theories of the SEM have been detailed in Section 3.2.3, specification of a SEM according to the research context will be illustrated in this section, as well as a statistical power evaluation.

6.3.1 SEM specification

Model specification is normally based on rational hypotheses, theories or past empirical evidence. In this study, as illustrated in Fig. 6-1, the assumed *a priori* specification is that young adults' current and changing usage of the Internet are hypothesised to impact their (current) environmental attitudes, travel choices, and pro-environmental behaviour. Such
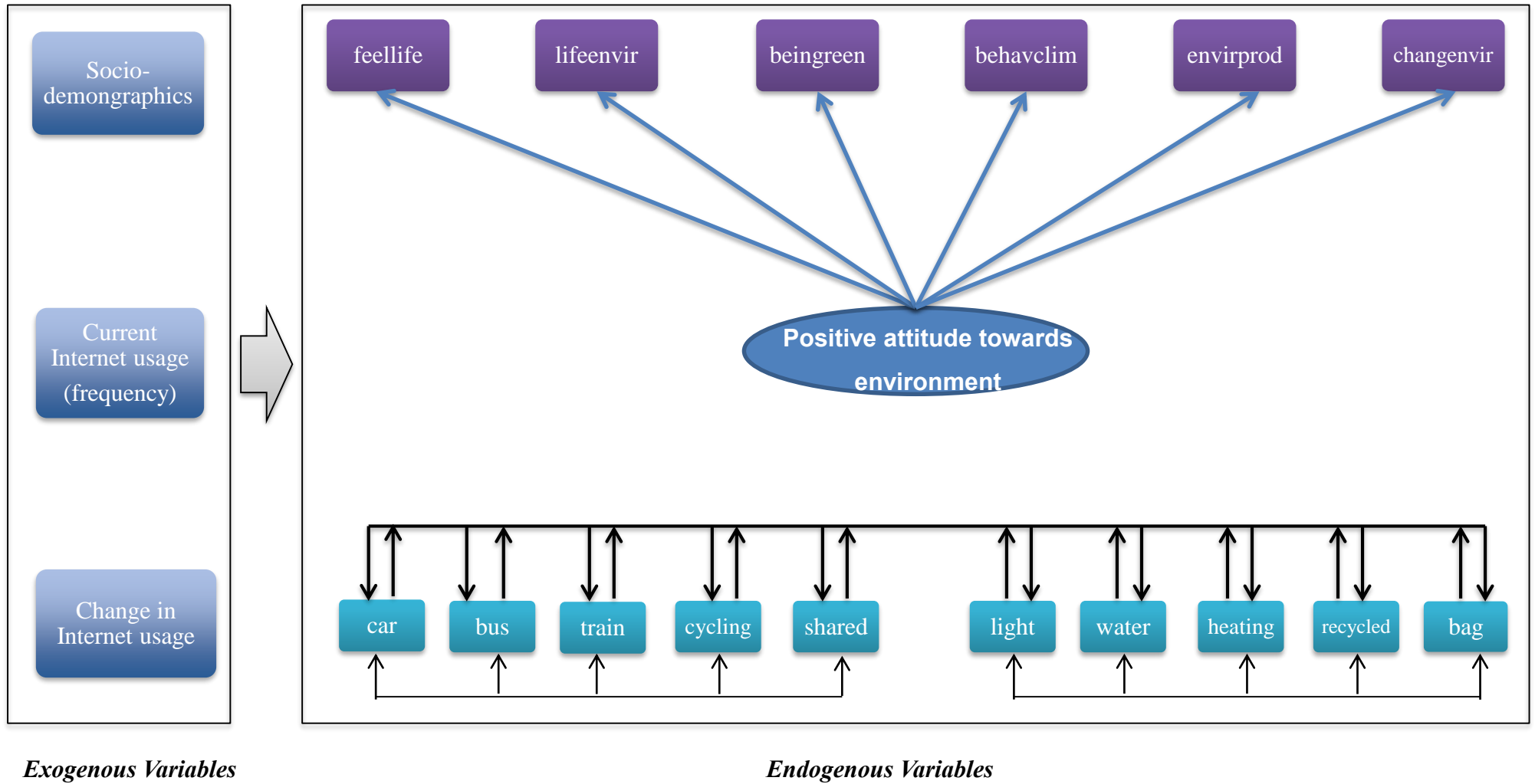
Fig. 6-1 Modelling framework (SEM)

an assumption is motivated and supported by the existence of various lower- and higher-order interactions between ICT and travel behaviour, as discussed in Chapter 2, and by the potential for ICT to influence people's environmental attitudes, as expounded at the beginning of this chapter. The assumption that people's past and changing use of the Internet affects travel behaviour is also empirically fuelled by many longitudinal studies on the ICT-travel relationships, and are also detailed in Chapter 2 (Section 2.3.2.3). Together with socio-demographic factors which are traditionally considered as the key determinants of behaviour and attitudes, current and changing use of the Internet were treated as the exogenous variables in the SEM model. Notably, when modelling the effects of current Internet use (represented by five indicator variables in terms of usage frequency), the indicator of *never use* was omitted as a reference. For changes in Internet usage, three indicator variables, *new*, *experienced* and *past heavy Internet users*, were included, with the indicator: *stubborn light users* referenced and omitted. Both socio-demographics and Internet use were therefore assumed as the exogenous variables, impacting behaviour and attitude in a unidirectional way.

However, the relationships assumed among the endogenous variables (the attitudinal and behavioural variables) are more complicated. As this study is interested in the role played in the ICT use-behaviour relationship by general environmental attitude, rather than by specific environmental concerns, a latent construct of *positive attitude towards environment* was firstly created based on the six observed attitudinal variables selected from the dataset so as to simplify the model structure and to clearly represent the attitude-related relationships. This treatment is commonly seen in travel behaviour studies

considering attitudes (e.g. Cao et al., 2007; Handy et al., 2005; Huang & Hsu, 2009; Kitamura, et al., 1997; Nilsson & Kuller, 2000). In terms of the relationship between attitude and travel/pro-environmental behaviour, classical behavioural theories, such as the theory of reasoned action (TRA), the theory of planed behaviour (TPB), and the value-belief-norm (VBN) theory, generally indicate that attitudinal factors determine behaviour. However, as discussed in Chapter 2, some theories, such as the self-perception theory (SPT), are seemingly counterintuitive as behaviour is assumed to precede and shape attitudes (Bem, 1972). In practice, the SPT has been applied to explain the interventions aimed at changing individuals' attitudes by making them experience certain travel choices (e.g. Fujii et al., 2001; Fujii & Kitamura, 2003). Accordingly, in addition to the effects of attitude on travel and pro-environmental behaviour, the potential effects in turn of behaviour on attitude were also assumed in the SEM model, which implies the adoption a non-recursive model. Moreover, correlations among travel choice behaviour and among pro-environmental behaviour were assumed as well since much empirical evidence has shown that individuals' choices among different travel modes are significantly correlated. For example, choosing to travel by car is always negatively correlated with the choice of using public transport (e.g. Anderson et al., 1992; Bamberg et al., 2003; Kuhnimhof et al., 2006; Thøgersen, 2006; Vij et al., 2013). Overall, as previously indicated, this SEM model is constructed as the combination of structural models and a measurement model for endogenous variables.

The specified model was run in the Mplus 7.0 environment. In terms of the estimation method of SEM, as discussed in Section 3.2.2, the robust WLS (weighted least squares)

estimators are preferred for this study since they do not assume normal distribution or require large sample sizes. In Mplus 7.0, two robust WLS estimators are provided, namely, the WLSM estimator, which produces a mean-adjusted chi-square, and the WLSMV estimator, producing a chi-square with both mean and variance adjusted. The WLSMV estimator was chosen for this study as 1) the WLSMV can generally perform well as long as the sample sizes are larger than 200 and variables are not markedly skewed (Muthén et al., 1997); 2) WLSM generally exhibits higher Type 1 error rates (Muthén et al., 1997; Muthén, 1999, 2003).

6.3.2 Statistical power evaluation

Determining the adequacy of sample size has received considerable attention in designing SEM-based studies as it is vital for ensuring an acceptable likelihood of gaining desirable empirical outcomes, particularly, statistical power and parameter precision (In'nami & Koizumi, 2013; Wolf et al., 2013). Statistical power refers to the probability of rejecting the null hypothesis when it is false, which can be perceived as the probability of not making the Type II error (i.e. 1- β) (Cohen, 1988). When determining the proper sample size for a study, researchers usually prioritise achieving adequate statistical power to examine true relationships in the data (Wolf et al., 2013), with the power of 0.80 (i.e. an 80% probability of rejecting a false null hypothesis) being a commonly used standard in the social sciences (Cohen, 1988). In addition, sample size can also affect parameter precision, model fit, and solution propriety (Gagné & Hancock, 2006), which is whether the number of cases is sufficient for a model to converge without improper solutions. Since this study

is fuelled by the analysis of second-hand data rather than first-hand data collection, the sample size is given. Hence, the efforts here are not to determine the sample size requirements for a SEM-based study design, but to examine whether the given sample size is adequate enough to achieve statistically desirable estimation.

A model-fit-index-based approach, as proposed by MacCallum et al. (1996), was adopted to estimate the statistical power of the specified model with a given sample size. According to MacCallum et al. (1996), by defining the null hypothesis in terms of the model fit index RMSEA (root mean square error of approximation), power can be computed for a SEM model given a sample size, significance (alpha) level, and degrees of freedom (*df*), without hypothesised population parameters. The sample size of this study is 792, the significance level (α) is normally set as 0.05, and RMSEA values of less than 0.05 generally indicate a good fit. The degrees of freedom were calculated based on the number of variables and free parameters revealed by the model specified in Fig. 6-1. The value is 161. The power computation is largely facilitated by a web-based utility programme developed by Preacher & Coffman (2006), which allows power analysis and sample size estimate for SEM to be conducted online (http://www.quantpsy.org/rmsea/rmsea.htm). As shown in Fig. 6-2, an *R* syntax was generated after specifying and submitting the information for alpha, degrees of freedom, sample size, null and alternative hypotheses of RMSEA into the *Compute Power for RMSEA* panel of the website. By implementing the syntax in *R* environment, the statistical power of the specified SEM model was computed as 0.993, which exceeds the well-accepted yardstick (0.80). The evaluation result suggests that the given sample size is adequate enough to ensure a statistically desirable outcome based on the specified model.

Compute Power for RMSEA

Alpha	0.05
Degrees of Freedom	160
Sample Size	792
Null RMSEA	0
Alt. RMSEA	0.05

Generate R Code

```
#Power analysis for CSM

alpha <- 0.05 #alpha level
d <- 160 #degrees of freedom
n <- 792 #sample size
rmsea0 <- 0 #null hypothesized RMSEA
rmseaa <- 0.05 #alternative hypothesized RMSEA

#Code below this point need not be changed by user
ncp0 <- (n-1)*d*rmsea0^2
ncpa <- (n-1)*d*rmseaa^2

#Compute power
if(rmsea0<rmseaa) {
    cval <- qchisq(alpha,d,ncp=ncp0,lower.tail=F)
    pow <- pchisq(cval,d,ncp=ncpa,lower.tail=F)
}
if(rmsea0>rmseaa) {
    cval <- qchisq(1-alpha,d,ncp=ncp0,lower.tail=F)
    pow <- 1-pchisq(cval,d,ncp=ncpa,lower.tail=F)
}
print(pow)
```

Submit above to Rweb	Erase R code

Fig. 6-2 Generation of *R* syntax for estimating the statistical power of the specified SEM model *(Based on a web-based utility programme developed by Preacher and Coffman)*

6.4 Modelling Results and Discussion

This section presents the key results of the modelling analysis and reveals findings based on the results. Furthermore, policy- and planning-related implications are also drawn on the basis of the main findings. According to the modelling approach (SEM) adopted in this study, this section is broadly divided into three main subsections in terms of result discussion. While the first subsection (6.4.1) is devoted to model evaluation and the results

of factor analysis, the second (6.4.2) is devoted to illustrating the interactions among endogenous variables. The third subsection (6.4.3), which is further specified in terms of the impacts of socio-demographics, current usage of the Internet, and changing usage of the Internet on attitudinal and behavioural variables, endeavours to elaborate both the direct and indirect effects of the exogenous variables on the endogenous variables specified in the SEM model. Final conclusions are then drawn based on the findings of the three subsections.

6.4.1 Model fit indices and standardised factor loadings

The goodness-of-fit indices are presented in the second half of Table 6-4, including chi-square (χ^2) with degrees of freedom (*df*) and p-value, normed chi-square (χ^2/df), TLI (Tucker–Lewis index), CFI (Comparative Fit Index), RMSEA (root mean square error of approximation) with the p-value of "close fit", and WRMR (weighted root mean square residual). Explanation of and the cut-off value for each index are detailed in Chapter 3. According to Table 6-4, almost every index indicates a model with good fit to the data, except for the χ^2 statistic which is significant at 324.461, implying rejection of the hypothesised model. As pointed out in Chapter 3, chi-square measurement has explicit limitations as it is highly sensitive to sample size, violation of normality assumption, and number of variables in model (Wang et al., 2012). The model is more likely to be rejected with a large sample size, a deviation from multivariate normality assumption, or a large number of variables. Despite this, χ^2 is normally reported since it is the basis for other

model fit indices (Byrne, 2001; Kline, 2005).

Table 6-4 Parameter estimates of factor analysis and model goodness-of–fit indices (N=792)

Factor	Observed Variables	Standardised Parameter Estimate
Positive Attitude towards Environment	feellife	.132**
	lifeenvir	.404**
	beingreen	.265**
	behavclim	.063**
	envirprod	.166**
	changenvir	.344**
Goodness-of–fit Indices	Chi-square=324.461 (d.f. =161, p-value=.000) Chi-square/d.f. =2.015 TLI=0.912 CFI=0.930 RMSEA=0.042, Pro.(RMSEA<=.05) =0.974 WRMR=0.092	

*(Note: ** Significant at the 5% level)*

The first half of Table 6-4 shows the parameter estimates of the six observed attitudinal indicators used for constructing the latent variable, i.e. factor loadings. Notably, the sizes of estimated parameters are inherently unit-dependent. For a better comparability between them in terms of, for example, magnitude of effect, all the estimated parameters derived from the SEM, including factor loadings, regression and correlation coefficients, are standardised. These standardised parameters are either Pearson product-moment correlation coefficients, in the case of continuous variables, or polychoric correlation coefficients, for ordered categorical variables (Jöreskog, 2002). It is clear from Table 6-4 that all the observed attitudinal variables can be significantly explained by the factor of *positive attitude towards environment* with positive loadings. Young people with a positive

attitude towards the environment are generally more likely to feel their current lifestyles are environmentally friendly. They are also more likely to accept "green" lifestyles and are more willing to change their behaviour to improve the environment if the changes fit in with their lifestyles.

6.4.2 Interactions among attitude, travel and pro-environmental behaviour

Interactions among endogenous variables are summarised in Table 6-5, which presents the standardised correlation and regression coefficient estimates. Since the bidirectional causal relationship has been assumed between attitude and behaviour, the coefficients estimated in the situation where attitude is treated as the causal variable are presented in the "attitude" line, while the results derived in another situation (i.e. attitude is the resulting variable) are listed in the "attitude" column. Similarly, the correlation coefficient between any two behavioural variables can be located in the table according to the line or column they head. Notably, as no relation has been theoretically assumed between travel choice and pro-environmental behaviour, their correlation coefficients are "not applicable" in the table. In general, the attitude construct, namely, positive attitude towards environment, positively influences young adults' sustainable travel choices, including less frequent car use and more frequent use of public transport and bicycles. Likewise, pro-environmental behaviour, i.e. energy saving and environmentally friendly purchasing, is also positively affected by attitude. In terms of the effects of behaviour on attitude, although travel choices and pro-environmental behaviour are not generally found to shape environmental attitude, less

Table 6-5 Standardised effects and correlations among endogenous variables (N=792)

	Attitude *(as resulting variable)*	car	bus	train	cycling	shared	light	water	heating	recycled	bag
Attitude *(as causal variable)*	n.a.	-.291**	.254**	.217**	.103**	.073	.139*	-.336**	.731**	.398**	.141*
car	-.287**	n.a.	-.233**	-.066*	-.112**	.116	n.a.	n.a.	n.a.	n.a.	n.a.
bus	.033	-.233**	n.a.	.165**	.041	.004*	n.a.	n.a.	n.a.	n.a.	n.a.
train	.051	-.066*	.165**	n.a.	.068**	.010	n.a.	n.a.	n.a.	n.a.	n.a.
cycling	.076**	-.112**	.041	.068**	n.a.	.001	n.a.	n.a.	n.a.	n.a.	n.a.
shared	.049	.116	.004*	.010	.001	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
light	.219	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	-.125**	.106**	.036	.017
water	-.377	n.a.	n.a.	n.a.	n.a.	n.a.	-.125**	n.a.	-.114**	-.057*	-.006
heating	.340	n.a.	n.a.	n.a.	n.a.	n.a.	.106**	-.114**	n.a.	.102*	.031
recycled	.057**	n.a.	n.a.	n.a.	n.a.	n.a.	.036	-.057*	.102*	n.a.	.108**
bag	.018	n.a.	n.a.	n.a.	n.a.	n.a.	.017	-.006	.031	.108**	n.a.

*(Note: n.a. = not applicable; *Significant at the 10% level; ** Significant at the 5% level)*

car use, more cycling, and more frequent purchasing of recycled products seem to contribute to people's positive attitudes towards the environment. This is consistent with some previous findings which revealed that pro-environmental behaviour may activate a general disposition, such as pro-environmental values, held by the actor. (Thøgersen & Crompton, 2009). As for the interactions among different travel choices, car use is negatively correlated with taking public transport and cycling, which is a common result found in studies on travel mode choices (e.g. Bamberg et al., 2003; Kuhnimhof et al., 2006; Thøgersen, 2006). In addition, traveling by train is positively correlated with travelling by bus and cycling. Moreover, most pro-environmental behaviour is positively correlated with one other, except for water use, which is negatively correlated with other behaviour as it is measured by frequency of water wasting.

6.4.3 Effects of exogenous variables on endogenous variables

Since attitude was assumed as the mediating variable in the model, exogenous variables may directly and indirectly impact travel and pro-environmental behaviour via attitude. Table 6-6 presents both the direct and total effects of exogenous variables, i.e. socio-demographics, (current) Internet usage, and past Internet experience with changes over time, on endogenous behavioural variables and attitudinal construct in the model. Results and findings are elaborated as follows.

Table 6-6 Standardised direct and total effects of exogenous variables on endogenous variables (N=792)

Exogenous Variables		Endogenous Variables										Positive Attitude
		Travel Choice					Pro-environmental Behaviour					
		car	bus	train	cycling	shared	light	water	heating	recycled	bag	
Socio-demographics												
sex	direct	-.145**	.056**	.010*	–	–	.114*	-.215**	.072*	.259**	.332**	.017*
	total	-.147**	.068**	.015*	–	–	.136*	-.216*	.033	.241**	.321**	.021*
age	direct	.057**	-.108**	–	–	–	–	–	–	–	–	–
	total	.051**	-.104*	–	–	–	–	–	–	–	–	–
kid0_4	direct	–	–	-.136**	–	–	–	–	-.185**	-.167**	-.273**	–
	total	–	–	-.139**	–	–	–	–	-.550**	-.333**	-.286**	–
kid5_15	direct	–	–	–	–	–	–	–	–	–	–	–
	total	–	–	–	–	–	–	–	–	–	–	–
adults	direct	-.128**	.185**	–	–	.113*	–	–	–	–	–	–
	total	-.133**	.189**	–	–	.117**	–	–	–	–	–	–
vehicles	direct	.421**	-.585**	-.136*	-.093**	-.161**	-.117*	–	–	–	–	-.007*
	total	.431**	-.594**	-.165*	-.106**	-.158**	-.122**	–	–	–	–	-.171**
income	direct	.376**	.113**	.063**	.007	–	-.008**	.027*	-.126**	–	–	.011*
	total	.397**	.119**	.081**	.015*	–	-.005*	.039*	-.157**	–	–	.013
parent	direct	-.164**	.231*	–	–	.322**	-.291**	.056**	-.271**	–	-.015**	-.094**
	total	-.272**	.234**	–	–	.344**	-.291**	.053**	-.381**	–	-.013*	-.091*
employed	direct	.217**	.186*	.186*	.306*	–	-.124*	–	–	–	–	–
	total	.206**	.191**	.228*	.301*	–	-.154*	–	–	–	–	–
student	direct	–	.038*	.419**	.207**	.123*	-.229*	.124	–	–	–	.617**
	total	–	.080**	.550**	.231**	.128**	-.206*	-.053*	–	–	–	.551**
licence	direct	.319**	-.216**	-.039*	–	-.146**	–	–	–	–	–	–
	total	.297**	-.205**	-.017*	–	-.135**	–	–	–	–	–	–
urban	direct	-.138*	–	-.112**	.060*	–	–	-.211*	–	–	–	.050**
	total	-.155**	–	-.119**	.077**	–	–	-.252*	–	–	–	.202**

(Continued)

Table 6-6 Continued

Exogenous Variables		Endogenous Variables										Positive Attitude
		Travel Choice					Pro-environmental Behaviour					
		car	bus	train	cycling	shared	light	water	heating	recycled	bag	
Internet Use												
interfreq2	direct	–	–	.047	–	–	–	–	–	–	–	–
	total	–	–	.052*	–	–	–	–	–	–	–	–
interfreq3	direct	–	.362**	.271*	–	–	.019	-.014	-.008	–	–	.227*
	total	–	.372**	.283**	–	–	.256*	-.322*	.168**	–	–	.257**
interfreq4	direct	-.306*	.774**	.729**	-.236**	–	.101*	.009	.035	.076*	.104**	.275**
	total	-.319**	.777**	.749**	-.231**	–	.470**	-.366**	.283**	.518**	.607**	.289**
interfreq5	direct	-.672**	.900**	.944**	-.238**	.086*	.134	-.004**	.005*	.012	.112	.405**
	total	-.697**	.874**	.913**	-.249**	.082**	.585**	-.614**	.428**	.576**	.585**	.623**
Past and changing use of Internet												
new	direct	–	.067**	.103*	–	.126*	.024	–	-.004	–	–	.335*
	total	–	.069**	.110*	–	.129*	.257*	–	.082*	–	–	.369*
expered	direct	-.102*	.192**	.165*	.073*	.134*	.056	-.012	–	.052**	.023*	517**
	total	-.228**	.365**	.345**	.181*	.248*	.393**	-.272*	–	.490**	.358*	.606**
past	direct	–	–	–	–	–	.005*	–	.014	–	–	–
	total	–	–	–	–	–	.007	–	.008*	–	–	–

*(Note: dash (–) = no significant direct or total effect detected; *Significant at the 10% level; ** Significant at the 5% level)*

6.4.3.1 Effects of socio-demographics

It can be seen from the first section of Table 6-6 that most of the socio-demographic characteristics show significant correlations with travel choices, pro-environmental behaviour, and attitude. Compared with males, young females tend to use cars less, take public transit more often, and are more environmentally friendly in general. They also have more positive environmental attitudes. Similar results have been commonly found in previous studies. In travel behaviour studies, females are found to be inclined to travel more often by public transport, by bicycle, or on foot, while car use tends to be higher among males (e.g. Flade, 1990; Howard & Burns, 2001; Matthies et al., 2002; Mäder, 1999; Stead, 2001; Schwanen et al., 2002, 2004; Zhang et al., 2008). This gender difference in mode choice is largely explained by the fact that women generally earn lower wages and undertake other jobs for non-work purposes (e.g. household maintenance tasks) (Hanson & Pratt, 1988; Johnston-Anumonwo, 1992; Madden, 1981; Turner & Niemeier, 1997). Another explanation comes from an environmental perspective, which suggests that females are more concerned about the environment than males, and thus, tend to adopt more sustainable travel patterns (e.g. Matthies et al., 2002; Polk, 2003, 2004). This argument is underpinned by many environmental behaviour studies, which indicate that women generally have stronger environmental concerns and beliefs than men do, and they tend to behave in a more environmentally friendly or "greener" way in daily life (e.g. Davidson & Freudenburg, 1996; Dietz et al., 1998; Scott & Willits, 1994; Stern et al., 1993). It seems that the gender differences in environmental attitude and behaviour patterns also exist in the millennial generation.

In terms of other socio-demographic factors, age is found to be positively correlated with frequency of car use, but negatively correlated with bus use. This is probably because young people are more likely to hold a driving licence or own a car as they get older. More children aged 0-4 in a household generally leads to less pro-environmental lifestyles for young people, with less conservative use of heating and less eco-friendly shopping. As revealed by several consumption studies, the presence of children tends to generate a household type with high consumption patterns (e.g. Brounen et al., 2012; Fell &Chiu, 2014). Moreover, young people from the households with more adults tend to less frequently travel by car, and more frequently travel by bus and rideshare. This could be attributable to a lower availability of car use for each household member, which increases the need to carshare and the probability of using other modes. In contrast, people from households with more vehicles tend to use cars more frequently and use other travel modes less. Furthermore, they exhibit less positive attitudes towards the environment, which, to some extent, implies that decisions regarding car ownership reflect environmental concerns (Flamm, 2006; Melia, 2011). Higher household income generally brings about more physical travel for young people, both by car and by public transport, as they are more capable of affording travel costs (e.g. car ownership, auto insurance, petrol consumption, bus/train tickets). Compared with the people living by themselves, those living with their parents tend to travel by car less, and take a bus or rideshare more often. It seems that young adults living alone are more likely to have their own cars, which can probably be ascribed to having a better financial situation (Dutzik et al., 2014); whereas those living with parents are more likely to share cars with their families and are less likely to save energy or to have an environmentally friendly

attitude. Compared with unemployed people, both the employed and students travel more frequently. While employed people tend to use the car more often, students are more likely to rideshare. Such preferences are possibly determined by their contrasting situations of financial independence. Moreover, students show more positive attitudes towards the environment. Possession of a driving license is positively related to frequent car use, but negatively related to use of other modes. Compared with those living in rural areas, urban dwellers tend to use the car and take trains less, but cycle more often, which is mainly attributable to their greater geographical accessibility to the sites of activity engagement (e.g. schools, shops, banks) in cities.

6.4.3.2 Effects of (current) Internet use

The second section of Table 6-6 shows that young adults' current Internet-use habits have significant impacts on their travel choices, pro-environmental behaviour, and attitude. Notably, the indicator variable *never use the Internet* was referenced in the model. In general, young people with high usage of the Internet tend to travel by car and by bike less frequently and take public transport more often. In particular, the negative effects of Internet use on car use and cycling are only detected for medium-to-heavy Internet users (i.e. use at least once per week or everyday), probably because they are more likely to substitute physical activities for virtual ones, thereby reducing travel. The transport's transition to the ICT-based activity engagement, such as teleworking, e-shopping, e-banking and online gaming, among young people with high dependence on ICT has been well documented (e.g. Lyons, 2015; van Wee, 2015), and supported by empirical studies

(e.g. Delbosc & Currie, 2013; Le Vine, 2014; McDonald, 2015; Vilhelmson & Thulin, 2008). This phenomenon is seen to greatly contribute to their low probability of travel and low car usage. On the other hand, since frequent Internet users may have more access to (and more reliance on) technology-enabled transport services in public transport systems, such as real-time bus information and on-board Wi-Fi, they are more likely to choose the bus and train as alternative travel modes (Davis et al., 2012; Dutzik et al., 2014; Garikapati et al., 2016; Martin et al., 2010). Additionally, heavy Internet users (everyday users) tend to rideshare more often compared with light users, which could be ascribed to their greater access to and dependence on smart technologies in daily life, such as car-sharing apps (Dutzik et al., 2013). As for the effects of Internet use on environmental behaviour and attitude, frequent Internet users tend to exhibit more pro-environmental behaviour in terms of energy saving and eco-friendly shopping, and have more positive attitudes towards the environment. Notably, in the causal relationship between Internet use and pro-environmental behaviour, the indirect effects of Internet usage, which are channelled through the attitude construct, account for most of the total Internet-induced effects. In other words, use of the Internet influences young adults' pro-environmental behaviour primarily via its impact on their attitudes towards the environment, which demonstrates the assumed mediating role attitude plays in the ICT-behaviour relationship. It seems that the Internet can cultivate and shape people's pro-environmental attitudes and awareness. This can happen by spreading environmental information and providing knowledge (Good, 2006; Nistor, 2010), by enhancing environmental activism (Allen et al., 2013; Pickerill, 2003; Stokols & Montero, 2002), and through online peer persuasion (Allen et al., 2013), thereby also influencing their behaviour.

6.4.3.3 Effects of past and changing usage of the Internet

As shown in the third section of Table 6-6, from a longitudinal perspective, young adults'
travel choices and pro-environmental behaviour, as well as their attitudes towards the
environment, are also related to their past Internet-use habits and changes in use over time.
More specifically, compared with the stubborn light users (referenced in the model), who
have never used the Internet on a daily basis, new heavy users, who recently started to use
the Internet every day, tend to take public transport and rideshare more often. As analysed
in the previous section, better access to transport technologies, which make alternative
modes more attractive and convenient, may explain such influences. The same
Internet-induced impacts on travel choices can also be found for experienced heavy users,
who have been using the Internet daily since they were adolescents. However, experienced
heavy users seem to have more sustainable travel patterns, as they also use the car less and
cycle more often, which is distinct from the new heavy users, whose usage of car and
bicycle is not significantly different from that of the stubborn light users. As for the past
heavy users, who dropped the habit of using the Internet daily, no significant distinction is
detected between their travel behaviour and that of stubborn light users, since they both
have low access to the Internet and technologies in their current daily lives. Attention
therefore needs to be paid to the experienced heavy users, and the distinctions between
new and experienced heavy users. Similar to the relationship between Internet use and
pro-environmental behaviour (also revealed in the previous section), the total effects of
sustained daily Internet usage on young adults' travel patterns are largely explained by the
indirect effects mediated by their environmental attitudes. This result is underpinned by

another fact that such sustained Internet use has a positive impact on the environmental attitude construct, which is more significant with a larger regression coefficient (0.606) compared with the effect caused by starting a habit of heavy use (0.369). In contrast with new heavy users, experienced heavy users have been exposed to the Internet since adolescence. The long-term exposure to the Internet starting from an early age plays an important role in their attitude and lifestyle formation, including their attitudes towards the environment (Allen et al., 2013; McMillan & Morrison, 2006). As much literature indicates, the Internet can potentially encourage and promote environmentalism through various approaches (e.g. Allen et al., 2013; Pickerill, 2003; Stokols & Montero, 2002; Zelwietro, 1998). Thus, intensive exposure to the Internet in the long term can profoundly shape young people's attitudes towards the environment, thereby directing their behaviour and choices towards more sustainable patterns. Such long-term effects on environmental attitude also significantly mediate the relationship between consistent heavy use of the Internet and pro-environmental behaviour. The result shows that experienced heavy users generally have more sustainable lifestyles (saving energy and eco-friendly shopping) compared with other user groups.

6.5 Summary and Policy Implications

6.5.1 Conclusions and discussions

This study demonstrated the use of longitudinal analysis to examine both the direct and indirect effects of current and past Internet usage on young adults' travel choices, pro-environmental attitudes, and behaviour. The focus is placed on the intermediary role attitude plays in Internet-induced effects on choices and behaviour, and how young people's past habits of Internet use and changes in usage over time impact on their travel and pro-environmental behaviour. The analysis draws on the British Household Panel Survey (BHPS) and the Understanding Society survey, which provide uniquely suited datasets recording individuals' behaviour, attitudes, and lifestyles at different ages. By merging the data of both surveys, a comprehensive dataset is created containing information about young people in both adolescence and adulthood. Aside from the multiple socio-demographic, attitudinal, and behavioural variables considered, a set of "experience" variables were created to represent young people's past and changing usage of the Internet.

Structural equation modelling (SEM) was applied to explore the complex relationships among variables. A latent variable – *positive attitude towards the environment* – was constructed first in the model, based on six observed attitudinal variables selected from the dataset. Other observed variables, i.e. (current and past) Internet usage, socio-demographics, travel choices and pro-environmental behaviour, were also included in the model along with their assumed interactions. The SEM results reveal three key relationships, one of which primarily addresses the research objective of this study, namely:

• Relationships between past Internet experience, attitude, and behaviour

Young adults' past Internet experience in adolescence influences their current travel choices and pro-environmental behaviour, and environmental attitude plays an intermediary role in the effects of consistent heavy Internet use on these choices and behaviour. More specifically, young people who have consistently used the Internet daily (defined as *experienced heavy users* in this study) are exposed to the long-term effects of the Internet from adolescence, which may shape their environmental attitudes and awareness more profoundly. Such attitude formation characterises their behaviour, which may be distinct from that of other young people. Although new heavy users, who started daily Internet usage later in life, tend to frequently use public transport and rideshare, these Internet-induced effects are largely due to their good access to and heavy reliance on technologies in their present-day lives. For experienced heavy users, however, their pro-environmental attitude, shaped by their long-term exposure to the Internet, greatly contributes to the total Internet-induced impacts on their choices and behaviour by acting as a mediator. As a result, they have even more sustainable travel patterns, with less car use and more cycling, and a more environmentally friendly lifestyle.

Two further findings, summarised as follows, also address two issues concerning this study:

• Relationships between attitude and behaviour

Young adults' positive attitude towards the environment is found to positively affect their sustainable travel choices, including less car use and more frequent use of public transport

and cycling, and their pro-environmental behaviour (energy saving and eco-friendly purchasing). Although environmental attitude is not generally shaped by sustainable choices and behaviour, less car use, more cycling, and more recycled product purchasing are found to contribute to people's positive attitudes towards the environment.

• Relationships between Internet use, attitude, and behaviour

Environmental attitude is significantly influenced by Internet usage. Young adults with high-frequency Internet use tend to have a more positive attitude to the environment and also behave in a more environmentally friendly way. By changing activity/travel patterns and providing more access to transport technologies, heavy Internet usage leads to a more sustainable mobility paradigm with reduction in car use and increase in using public transport and ridesharing. In addition, pro-environmental behaviour patterns are also expected if young adults use the Internet frequently. However, the direct Internet-induced effects on pro-environment behaviour are not dominant. Instead, the indirect effects mediated by environmental attitude play a significant role in the Internet–behaviour relationship.

Apart from the interaction among Internet use, attitude, and behaviour, which is the main interest of this study, conclusions can also be made for the correlations of socio-demographics with attitude and choices/behaviour, and for the correlations with behaviour:

• *"Spill-over" effect*

There are positive correlations among sustainable travel choices and among pro-environmental behaviours, which shows that environment-friendly behaviour has a tendency to "spill over" into other behavioural domains (Frey, 1993; Thøgersen, 1999). Such "spill-over" effects in relation to pro-environmental behaviour (Whitmarsh, 2009) are also conceptualised as "catalyst behaviours", which implies that starting a new behaviour (such as recycling) may lead to the adoption of other environmentally-beneficial behaviour (Austin et al., 2011). Several psychological and behavioural theories back this effect, such as the balance theory and the dissonance theory, claiming that people have a need to avoid inconsistencies in their beliefs, attitudes, and behaviour (Eagly & Chaiken, 1993). The self-perception theory additionally predicts that taking up pro-environmental behaviour in one area changes people's attitudes in a way that increases their 'preparedness to behave environmentally friendly in other areas' (Thøgersen & Ölander, 2003).

• *Gender*

Females generally have more positive attitudes towards the environment than males do and tend to have more sustainable travel patterns and behave in a more environmentally friendly way. Such gender differences in environmental attitude and behavioural patterns are also seen in the millennial generation.

• *Number of children aged 0-4 in household*

As child-rearing leads to a household type with high consumption patterns, young people from the households with more children aged 0-4 tend to behave in a less environmentally friendly way.

• *Vehicle ownership in household*

Higher vehicle ownership in households not only leads to less sustainable travel patterns (i.e. more car use and less use of other modes) among young people, but also contributes to their forming less positive attitudes towards the environment.

• *Living with parents or not*

Young adults living by themselves are more likely to have their own cars and therefore travel by car more often; whereas those living with their parents tend to share cars with their families, more frequently take buses, and are less environmentally friendly in terms of attitude and energy use.

• *Employment status*

Due to their financial independence, employed young people tend to travel by car more often, while students are more likely to rideshare while also exhibiting more positive attitude towards the environment. Both the employed and students generally travel more often than the unemployed.

6.5.2 Policy and planning implications

The results of this study generally indicate that there is a decrease in car use with the adoption of ICT, which reflects the emerging transport phenomenon labelled "peak car" or

"peak travel" (Goodwin, 2013). Young people's travel patterns, as exemplified in this study, can be well explained by this "peak car" phenomenon. Apart from situational factors, such as economic recession, high unemployment, increasing petrol prices, the high cost of acquiring a driver's licence, and the decreasing status of the car, the increasing adoption of and dependence on ICT-based services may have greatly contributed to this trend, especially among young people who are regarded as "digital natives". Accordingly, arguments have been made that in the digital age, a transport transition towards more ICT-based activity patterns and accessibility would be expected, particularly among the millennial generation, and "peak car" is the first sign of such a transition (e.g. Lyons, 2015; van Wee, 2015). Along with the increasing development and adoption of ICT-enabled transport services in public transport and ridesharing, an increase in use of alternative modes would also characterise the transition. Transport planners and policy-makers are therefore strongly advised to carefully (re-)evaluate the demand for automobile transport and the provision of public transport to adapt policy strategies to this emerging transport transition, as it creates great opportunities for achieving sustainable mobility. Moreover, the strategic roles of ICT in delivering sustainability could be further explored. Current policy strategies aimed at inducing changes in people's travel behaviour through ICT mainly employ the immediate or first-order effects of ICT (e.g. substitution, generation, modification) on physical travel. In the future, the long-term or higher-order effects of ICT, which may indirectly but profoundly change mobility behaviour by influencing people's attitudes, could also be applied in policy-making.

Chapter 7 Conclusions

The roles of ICT on physical mobility have received great attention recently in both transport studies and policy making. The potential of ICT to deliver a more efficient and "smarter" transport system and to fulfil people's activity needs in virtual reality are always highlighted in research and policy agenda as they are expected to fuel the pursuit of sustainability in the transport sector and in urban environments, especially in this information age. Although a large body of research focusing on travel demand and behavioural aspects has contributed greatly to our understanding of ICT-travel interactions, some areas are still underexplored. For instance, what are the exact implications of ICT-travel interactions for certain segments of the population characterised by specific personal, household, and social attributes? How do such interactions change over time as a result of the rapid evolutions in technologies? Does people's past ICT experience influence their current travel patterns? Since attitudes normally determine behaviour, does use of ICT indirectly impact people's travel behaviour by changing their attitudes? These questions have motivated this thesis' attempts to extend the scope of current research to gain further insight into the diverse roles of ICT in shaping mobility behaviour. Thus, the three principle research objectives were pursued using various analytical techniques, leading to several evidence-based contributions to existing literature, which are discussed in Section 7.1. The key policy and planning implications of the research findings are subsequently addressed in Section 7.2, followed by an indication of research limitations and potential directions for future work (Section 7.3).

7.1 Main Research Findings and Contributions

Addressing the three objectives has led to the uncovering of a large number of findings. This section summarises the key ones in terms of the interactions between ICT use and travel behaviour, as well as their behavioural and methodological contributions to transport research.

• *The ICT-travel relationships differ according to household working status*

This finding was suggested in Chapter 4, where a cross-sectional attempt was made to address Objective A. More specifically, use of the Internet (for non-work purposes) generally has complementary effects on people's maintenance-related activity-travel behaviour, and these effects differ among the workers and non-workers from different types of households as categorised by household working status. While non-workers' mobility behaviour is always significantly affected by use of the Internet, regardless of the group differences, the significance of such Internet-induced impacts on workers' activity-travel patterns depends on whether or not the individuals perform the maintenance tasks; moreover, they are more likely to perform the tasks as the household worker ratio (i.e. number of works/total adults in a household) increases. In addition, due to the intensive time constraints mainly imposed by work, workers were found to have different behavioural responses than non-workers to adoption of the Internet. Workers who undertake maintenance activities, to whatever extent, tend to substitute physical maintenance pursuits with online activity performing (e.g. e-shopping and e-banking) if

they spend a long time on the Internet. This finding suggests that the ICT-travel relationships are likely to be characterised by individual working status and intra-household interactions, which, as much literature has revealed, impose different constraints on individuals' non-work mobility patterns. Wider implications for the roles of ICT in shaping mobility are drawn, with consideration of their effects at both the individual and household levels.

• *The ICT-travel relationships differ according to generation*

Apart from household working status, another factor potentially characterising the ICT-travel relationships is generation, as was uncovered in Chapter 5. As illustrated in Chapter 5, use of the Internet tends to complement maintenance-related travels for the general adult population, though the substitutive interaction between ICT use and travel is seen among the heavy Internet users in more recent years. By contrast, for millennials, use of the Internet generally has negative effects on their activity-travel time use for both maintenance and leisure purposes even at the earlier point. This finding implies that while the general population is likely to utilise the Internet to facilitate physical mobility for maintenance purposes, millennials are inclined to substitute physical non-mandatory activities (maintenance and leisure activities) with online pursuits. As digital natives, born and raised in the digital age, millennials' heavy reliance on ICT in their daily lives to a large extent shapes them as a "go-nowhere" generation.

• *The ICT-travel relationships evolve over time*

This finding was highlighted in Chapter 5 when addressing Objective B. Derived from a

repeated cross-sectional analysis, the finding suggests that the ICT-travel interactions in terms of non-mandatory activity purposes changed over the decade (2005/06-2015), and the changes are generally characterised by diminishing complementarity and increasing substitution. In other words, as a result of rapid technological evolution over time, ICT are more likely to act as a discourager rather than as a facilitator in shaping individuals' activity-travel patterns. In addition, the finding further points out that the ICT-travel relationships evolve differently for millennials. Such temporal changes are only found to be significant within the general adult population among the medium-to-heavy Internet users, spending over 5 hours online per week, leading to a new ICT-travel interaction of substitution instead of complementarity or neutrality. By contrast, among millennials, only the light Internet users (no more than 5 hours' usage) or the medium-to-light users see significant temporal changes. As for the young heavy users, who already greatly substituted their physical pursuits with virtual ones at an early point in time (2005/06), they may not further reduce their engagement in out-of-home activities and travels, regardless of the increasing opportunities for substituting mobility brought about by technological evolution.

• *Long-term exposure to ICT may shape travel behaviour by influencing attitude*

This finding was derived from the longitudinal analysis performed in Chapter 6, where the effects of past Internet usage in adolescence on young adults' current travel choices and pro-environmental behaviour were examined as well as the intermediary role that attitude plays in the ICT-travel relationships. Objective C was addressed accordingly. The finding reveals that for the young people who maintained a heavy Internet use habit formed in their

adolescence (i.e. the experienced heavy users), their pro-environmental attitudes are profoundly shaped by their long-term exposure to the Internet. The attitude, hence, acts as a mediator, indirectly and greatly contributing to the effects of Internet use on these young adults' travel choices and pro-environmental behaviour. As a result, these experienced heavy users tend to have more sustainable travel patterns and lifestyles. Rather than suggesting the simple and direct interactions of complementarity or substitution between ICT and travel, analysis taking a longitudinal point of view can get more insights into the higher-order interactions, which in this case are mediated by attitude.

7.2 Summary of Policy and Planning Implications

The results of travel behaviour analysis can lead to a number of recommendations for policy and planning actions that highlight the role of ICT in achieving sustainable mobility. The key policy implications are summarised as follows:

• *Moving beyond travel substituting*

Despite triggering a growing interest in ICT-travel interaction, the potential of ICT to substitute people's physical activity participation and travel has traditionally been overemphasised in both research and policy agendas. As the results of this research and those of many recent studies have demonstrated, this potential for substitution is overestimated, and ICT can also complement or generate physical travel. With the uncovering of the complicated mechanisms through which ICT interact with travel

behaviour, the focus of policy making may need to move away from simply reducing or substituting travel demands by facilitating ICT adoption towards exploring how ICT can enhance people's travel efficiency by, for example, reducing travel duration and distance or facilitating multitasking. Compared to relying on the ambiguous effects of substitution or complementarity, maximising the potential of efficiency enhancement would appear to be more promising in the pursuit of sustainability.

• *More specific strategies for targeted groups*

Existing policy actions that bring ICT elements into sustainable transport planning tend to produce generalised measures or guidelines for the public, with limited consideration of the complexity of the ICT-travel interactions. As suggested by this research, such interactions may significantly differ according to personal, household, and social attributes, such as gender, working status and generation. Therefore, unified actions employing the interaction mechanism are unable to accommodate the diversity of behavioural responses and lead to low policy efficiency. Accordingly, it is recommended that policy strategies be elaborated to target specific groups, such as workers, millennials, and the elderly. In order to do this, policy-makers and planners need to have more accurate and holistic predictions of travel demands for specific individual and household types, instead of simply making an overall estimation for the general population.

• *Linkage of ICT and transport policies*

The importance of linking ICT with transport planning has been well recognised in current policy actions, and both technological and behavioural interventions have been widely

implemented. Nevertheless, at the ideological level, there is a lack of emphasis on the linkage between the two policy domains in terms of ICT promotion and sustainable transport planning which needs addressing. In terms of digital citizenship, alleviating the digital divide and encouraging digital inclusion are prioritised in current information and digital policy agenda. Fuelled by rapid evolution in technologies, this policy orientation will lead to a wider application and proliferation of ICT and a more digitalised and connected world. The expected policy effects could, therefore, create more possibilities and better prospects for the adoption of ICT-based strategies in sustainable transport planning. In turn, transport planning strategies, such as "smart" transport and "soft" measures for changing travel behaviour, would facilitate ICT adoption and the transition towards digitalisation. Clearly, such policy linkage can potentially enhance the efficiency of policy implementation.

• *Applying the higher-order ICT-travel interactions*

As highlighted in this thesis, research and policy attempts have predominantly focused on the immediate and direct ICT-induced effects on travel behaviour, namely, the first-order interactions, paying limited attention to the higher-order ones, which are less tangible and subtler. However, the higher-order interactions may have more far-reaching implications for behavioural changes. As reviewed and revealed by this research, ICT can affect travel behaviour by influencing, for example, urban forms, lifestyles, perceptions, and attitudes. Since ICT are penetrating deeper into people's daily lives and reshaping their mobility patterns, it is necessary for planners and policy-makers to take a long-term perspective to explore the more profound roles ICT can play in delivering efficiency and sustainability in

the transport sector.

7.3 Limitations and Recommendations for Future Research

Although the results and findings obtained in this thesis provide novel insights into the interactions between ICT and mobility behaviour, they are not exempt from limitations that could, nevertheless, be seen as potential avenues for future research.

The first limitation arises from the ICT elements considered in this research. Although travel behaviour has been measured diversely, in terms of activity purposes, travel time, mode choice, and trip frequency, in the three analytical chapters, only the general use of the Internet has been considered to represent the ICT element. Since ICT are penetrating ever deeper into people's daily lives in various ways, the diversity of the ICT-travel interactions would be further revealed if use of ICT were specified in the model in terms of, for example, purpose of usage (e.g. maintenance and leisure purposes), method of accessing (e.g. personal computers, laptops, and mobile phones), and place of accessing (e.g. home, workplace, and school).

In addition, improvement could also be made by considering the effects of ageing on millennials' travel behaviour, as well as its interactions with use of ICT. In Chapter 5 of this thesis, the millennial sample included in the 2005/06 survey is generally younger than that in 2015. The younger millennials may have behavioural patterns that are distinct from

those of the older millennials, which can be seen in the different effects of the number of children in a household on their activity-travel behaviour, as revealed in Chapter 5. Additionally, since only young millennial adults with a narrow age range (18 to 24) were considered in the study in Chapter 6, the findings might not necessarily explain the situations of the older millennials. In other words, if a longer period were taken into account, more and older millennials would appear in the sample, potentially leading to different research findings. In fact, some studies have shown that older millennials may exhibit mobility patterns that are similar to those of their prior generation's counterparts, but different from their younger counterparts in their own generation (e.g. Garikapati et al., 2016; Thakuriah et al., 2010). Due to the effects of ageing, the ICT-travel interactions among millennials might differ according to age; this needs to be further examined.

Another direction which could be pursued in the future is to consider other advanced modelling techniques which could potentially lead to a simple and parsimonious model structure. For instance, as individuals' participation decision in different types of activities within a given time period and the duration in the chosen activities are characterised by the choice situation of multiple discreteness (i.e. the simultaneous choice of multiple alternatives from a set of alternatives that are not mutually exclusive) (Pinjari & Bhat, 2010), the multiple discrete–continuous extreme value (MDCEV) model, which has been recently developed by Bhat (2005) and based on introducing a multiplicative log-extreme value error term into the utility function, could be employed to analyse the time-use allocation decisions among different activities (e.g. maintenance activities and leisure activities) in a direct way. Since it was developed, the MDCEV model as well as its

variants has been successfully applied in the modelling context of individual time-use in multiple activity pursuits (e.g. Bhat, 2005; Castro et al., 2012; Pinjari & Bhat, 2010). In addition, the multivariate analysis, which estimates a single regression model with multiple outcome variables, could be employed to jointly model the four activity-travel variables (i.e. activity-travel time-use for maintenance and leisure purposes, respectively) included in the studies in Chapter 4 and 5. In doing so, the modelling procedure would be simpler than using separate OLS regression analyses for each outcome variable. Moreover, in terms of modelling the dependent variable with excessive zeros, the zero-inflated model, which is based on the zero-inflated probability distribution, could be an alternative to the 2PM (two-part model).

Finally, this research principally focuses on the behavioural or demand side of the ICT-travel interactions. Meanwhile, the supply side of such interactions is also diverse and is undergoing dynamic evolution, especially in the ITS (Intelligent Transport Systems) field (e.g. travel time predictions, location-based services, and autonomous driving). Although this research has theoretically incorporated some of these developments, further efforts can be made empirically to integrate the interactions on both sides so as to provide a comprehensive assessment of the roles of ICT in shaping urban mobility in this information age.

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