# *Chapter 9: Summary, Discussion and Conclusions*

This final Chapter contains six Sections. The first Section summarises the thesis, chapter by chapter. The second Section presents conclusions from the case studies. Sections 3 and 4 suggest general and policy implications respectively. Section 5 discusses methodological lessons and Section 6 briefly indicates directions for further work.

## *9.1 Summary*

This project has investigated the dynamics of the relationship between personal communications and travel, using agent-based computer modelling and simulation. It focused on the interaction between social, communication and transport networks. It covered person-to-person social communication (i.e. with friends and family) that is mediated by a communications network (such as the postal service or email) or involves a journey, mediated by the transport network. It did not cover broadcasting, nor business-related communication and travel, such as commuting or shopping. The thesis aimed to provide a better understanding of why communication and travel have grown together, and to address the question "why are communication and travel complements, not substitutes?" This is an important question to those who are interested in the impact of new communication and transport technologies on society, and to those who are concerned about the environmental impact of the continuing growth in travel.

### Chapter 1: Theory and Methodology

This Chapter opened with a discussion of the relationship between individuals, society and emergence. It noted ideas about society: as a three stage vertical hierarchy (micro, meso and macro), as based on the agency-structure duality and more recently, as intersecting networks. It concluded that there is agreement that individuals interact to produce society which in turn influences them and that society could be seen as a dynamic, emergent social phenomenon created by the interaction of individuals.

A model was defined as a set of explicit, quantifiable statements that describe a process and the benefits of using such models were discussed. It was argued that building models is important in promoting the scientific analysis of social phenomena and can assist constructive thinking about a question in two ways. First, the act of modelling encourages clarification of both the concepts and the theory and helps to formulate questions. Second, the outputs of the modelling process may improve our understanding of social phenomena and help to formulate further questions and data requirements.

It was explained that agent-based modelling was chosen for this thesis because it offers a way of studying how individuals and society interact, unlike the alternatives, systems dynamics and microsimulation. Part of the novelty of this thesis lies in using this new modelling technique, which has not been used extensively in the modelling of transport and communications. The principles that underlie the building and testing of agent-based models were set out and it was concluded that to be acceptable the model must pass the macro goodness-of-fit test and be based on justifiable micro assumptions. Finally, it was explained that NetLogo was chosen to implement the models in this thesis due its suitability for those who are not experienced programmers.

## Chapter 2: Time and Money

By way of introduction to the long-term trends, Chapter 2 addressed three questions:

- to what extent are communication and travel limited by time and money?
- are communication and travel necessities or luxuries?
- how are expenditure on communications and travel related?

It concluded that from 1840 to the First World War, money was the key constraint on the consumption of both communication and travel. The consumption of travel seems to have reached 'saturation' in terms of both time and money but this limit appears not to have been reached for communications. Expenditure on communications remains a small part of household budgets. Furthermore, it is impossible to look at the time spent communicating in the same way as time spent travelling because communicating is part of almost everything we do. It is conceptually and practically impossible to measure time

spent communicating. Nevertheless, there is a willingness (noted by Harper, forthcoming) to continue to adopt new means of communication.

Rising standards of living have meant that the poor in a subsequent era can consume things only available to the rich in a previous era. In the nineteenth century, both communications and travel were luxuries but while some travel, at least, remains a luxury, communications have become a necessity.

There is a popular perception that transport and communications are substitutes. Yet the simple fact that real expenditure (i.e. after adjusting for inflation) on both communication and transport have both increased over time suggests they are complements. More sophisticated analysis tends to confirm this view. This is discussed further in Chapter 5,

## Chapter 3: Networks

Chapter 3 set out the differences between transport, communication and social networks. Both transport and communication networks comprise physical links but social networks are conceptually different in that they are representations of relationships. Yet communication networks grow out of social networks; and so, less directly, do transport networks in that they link centres of population.

The Chapter then examined how networks are modelled. It noted that four basic types of network model are found in the literature; regular lattice, random linking, small world, and preferential attachment (or scale-free). It concluded that these standard network models could be used to describe transport networks. However, communication networks tend to reflect the underlying social networks.

Ideally a model of a large social network should have the following key characteristics:
- a low whole network density, i.e. only a very few of the potential links in the network should actually exist;
- positive assortativity by degree of connectivity i.e. those with large personal networks tend to know others with large personal networks;

- communities, i.e. groups of people that are well connected to one another but loosely connected to other groups;

- short path lengths, i.e. others can be reached in a small number of steps.

Personal (or ego-centred) networks should:

- be of limited size, the limit depending on the type of relationships being studied;

- vary between individuals, with a fat-tailed distribution of degree of connectivity except for close associates;

- display high clustering, i.e. friends tend to know each others friends;

- change over time.

On this basis, none of the standard network models represent social networks well.

## Chapter 4: A New Model of Social Networks

Chapter 4 introduced a new method to create large social networks in agent-based models using social circles (as first described in Hamill & Gilbert, 2009). Based on the idea of social circles, this model can produce the key features of personal and social networks identified in Chapter 3. By varying the parameters of the model, it is possible to produce a variety of societies. The concept of socialshifting was introduced, whereby agents move small amounts to reflect changes in their social positions. This model was then used as the basis for the case studies.

## Chapter 5: A General Model

Chapter 5 started by noting that the word 'substitute' seems to be used rather differently by economists than by sociologists or in everyday parlance. In economics, substitution is about choosing between options; but in sociology, it is said that communications substitute for meeting someone face-to-face even when such a meeting is not an option. It maybe that in such circumstances communication by letter or mobile is a 'second best solution' in the economic sense because a letter or a phone call is better than no communication. Because the term is being used in this broader sociological sense perhaps explains why the idea that communication and travel are substitutes is so pervasive. There is, however, little support for the substitution hypothesis in the stricter economic

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sense. In the longer term communications and travel are complements in the economic sense, because more relationships can be maintained over greater distances and thus the demand for both travel and communication rise together.

Chapter 5 then built on the social network model presented in Chapter 4 to address the question raised in the Introduction about the relationship between communications and travel. A general model was presented that could be adapted to use in each of the three case studies that follow: the model focuses on the interaction between social and communication networks, with travel being taken as an outcome. Specifically:

- the environment is a social space which reflects an agent's intentional personal network, defined as comprising those with whom the agent makes an effort to remain in contact and for whom there is a direct relationship between the strength of tie and the amount of communication.
- the agents can represent individuals or households and possess demographic, socio-economic and other characteristics including skills. Agents age and die, their income may change and they may become more skilled. The size and membership of their personal networks may change due to socialshifting and death.

To this basic structure is added the adoption and use of new communications technology. Adoption depends on the availability and affordability of the technology, the agent's skills and the influence of the agent's personal network and of society as a whole. The model of use identifies seven factors resulting from the introduction of a new mode of communication, four affecting the pattern of communications and three affecting travel.

- A new communication mode is used to send messages to those already in an agent's personal network, the social solidarity effect.
- Older communication modes are used less, the communication substitution effect.
- A new mode of communication also generates new practices.
- It can also change personal networks by enabling contact to be maintained with those with whom otherwise it would have been lost, or even to generate new contacts, the global village effect.

- More communication results in more travel to enable face-to-face contact, the travel complementarity effect.

- More travel results in more communication to arrange that travel, the travel communications effect.

- Finally communication may reduce the need to travel, the travel substitution effect.

## Chapter 6: Mail and Rail

Chapter 6 presented a case study of the adoption and use of mail and rail services from 1840, when the universal Penny Post was introduced, to the start of First World War. While there is much evidence to suggest that British society was mobile before 1840, after 1840 the new mail and rail services permitted communication and travel on an unprecedented scale. The railways expanded across the country and the Parliamentary trains greatly stimulated the demand for travel, much of which appears to have been private rather than business, as was much of the mail.

Using the social network model described in Chapter 4 and the general model developed in Chapter 5, an agent-based model was developed to reproduce the tenfold increase in mail per head and thirtyfold increase in rail journeys per head by combining data on demography and economic growth, and the spread of access to mail services and of literacy. Migration was an important feature of life in this period, and the new communications and transport technologies meant that literate people who could afford to do so could maintain at least some of their contacts when they moved. To represent migration the model incorporates large jumps that seriously disrupt personal networks, which were partially preserved through the new technologies. It also allows for socialshifting, much less disruptive small steps (as discussed in Chapter 4). There was no allowance for communication substitution effect because, when the universal Penny Post was introduced, travel to meet face-to-face was, for most people, the only alternative to sending a letter. Nor is there any allowance for the substitution of letters for travel as there is no evidence to support such an effect. The model was validated by examining the effect of four unrealistic assumptions, concerning the Gini coefficient, affordability,

economic growth and literacy. In all four cases, the model produced results quite different from those produced by the base case.

The model suggests that:

- Sending messages to those in existing personal networks was the key driver of demand for mail services.

- New practices arose, particularly involving the sending of cards.

- By enabling people to maintain contacts that would otherwise have been lost – the global village effect – the universal Penny Post increased personal networks by 9 percent overall; by 15 percent for those who were literate, had access to the mail system and could afford to use these services. This represents an additional 3 to 4 people.

- Up to about 1875, the use of mail services was restricted by lack of literacy and lack of access; after that, literacy and access were no longer constraints, but poverty restricted their use.

- The rise in the use of mail and rail per head far outstripped growth in GDP per head, primarily due to the growth in the number of people who were able to use the new services.

## Chapter 7: Phones and Cars

Chapter 7 presented a case study of the adoption of phones and cars by households over a 50 year period, from 1951 to 2001. There is insufficient data with which to validate a model of the use of phones after the privatisation of BT in 1984, or the use of cars, because most car travel was not for social use. The aim of the model is therefore to reproduce adoption, but not use. Although based on the general model described in Chapter 5, the model nevertheless differs from that in Chapter 6 in many respects: in particular, agents represent households. The model reproduces the key demographic change over this period, namely the trebling of the proportion of single-person households, and takes into account not only rising real incomes but also the growth in the economic activity of women, unemployment, early retirement and one-parent families. Migration is not explicitly modelled but mobility is assumed to be part of middle and

upper class culture and households are clustered by social class; class also determines income. Socialshifting is again used. Different models of diffusion are applied to phones and cars. For cars, adoption depends only on economic growth and the fall in the relative price of motoring. For phones, adoption depends very little on affordability but rather on personal networks, implicitly on social class and, by implication, mobility. This reflects the fact that there is little point having a phone if your friends and family do not also have phones and that, compared to cars, phones are relatively inexpensive. The model assumes that phones were adopted first by the upper and middle classes, and spread by households influencing a very few other households, reflecting the fact that phones are used for regular contact with a few core ties. Although the digital revolution started in the 1990s, this is not taken into account. The model was validated by comparing the resulting adoption curves with the actual adoption observed and sensitivity tests were carried out.

The model broadly reproduces the observed pattern of phone and car adoption between 1951 and 2001. The model demonstrates how the physical phone network could have been created by the social network while the adoption of cars could be reproduced by economic growth, constrained by financial costs and the ageing population. Although the use of the phone and car were not modelled, the Chapter reviewed the literature following the structure of the model in Chapter 5 and concluded that phones were substituted for letters and promoted travel by facilitating arrangements. A little evidence of phone calls being substituted for travel was found.

## Chapter 8: Mobiles and the Internet

Chapter 8 drew not only on Chapters 4 and 5, but also on the models described in Chapters 6 and 7 to produce a model of the adoption and use of mobiles and communication using the internet from 1998 to 2007, and then projected forward to 2021. In this model, agents represent individuals that have access to household income. Adoption depends on affordability and 'digital literacy', which in turn depends on class and age. Digital literacy is also affected by social pressures, from both personal networks and society at large. The model also suggests that the age and class distribution of digital literacy created a core group of internet adopters, a critical mass, who facilitated the

spread of the internet through network effects. For internet communication, use also depends on the degree of social mobility. The same model was used for both mobiles and the internet, with different parameter values. The model incorporates the key difference between internet communication and modes that have gone before: the ability of the internet to facilitate the making of new friends.

The model reproduces the growth in adoption of mobiles and internet communication between 1998 and 2007 well, including the distribution across age and income bands and classes. It broadly replicates the observed growth in voice calls from mobiles but significantly understates the growth in texting. Because there is no data against which to validate the use of the internet for communication over this period, the model focuses on the growing importance of online links. This model was then used to extrapolate to 2016 and 2021.

The model suggests that the adoption and use of both mobiles and the internet can be attributed to the spread of digital literacy skills, both through the generation effect, as older generations are replaced by younger more digitally literate generations, and through personal networks. For mobiles, the model suggests that:

- mobiles have significantly increased contact with pre-existing personal networks;
- by 2016 the adoption of mobiles will have reached saturation at almost 95 percent;
- the number of text messages sent will continue to increase significantly to 2021.

For communications over the internet, the model suggests that:

- internet communication will have permeated personal networks by 2021, being used for three-quarters of all links;
- communication through the internet has increased the size of personal networks in a manner that earlier communication modes were unable to do because it allows people to meet new people, adding 15 percent to personal networks by 2021, representing an extra 4 people.

Finally, the model predicts that even by 2021, an important minority will be excluded from this 'digital world' of communications, especially those aged 75 and over.

## 9.2 Conclusion: Communications and Travel

Table 9.2.1 summarises the results of the three case studies.

**Table 9.2.1: Summary of the key characteristics of the three models.**

| | Chapter 6 | Chapter 7 | Chapter 8 | |
|---|---|---|---|---|
| **Aim** | | | | |
| Communication | Mail | Fixed line phone | Mobile & internet | |
| Travel | Rail | Cars | Unspecified | |
| Time period | 1840-1913 | 1951-2001 | 1998-2021 | |
| Target | Use | Adoption | Adoption & use | |
| **Model** | | | | |
| Agents | Individuals | Households | Individuals | |
| Attributes | | | | |
| Location | Random | Grouped by class | Grouped by class | |
| Demographic | Age | Age, type, size | Age | |
| Socio-economic | Income | Class, income, economic status | Class, income, economic status | |
| Skills | Literacy | None | Digital literacy | |
| Personal networks | Yes | Yes | Yes | |
| Dynamics | | | | |
| Demographic | Birth & death | Birth, death, household changes | Birth & death | |
| Income | Growth | Growth, economic status | Growth, economic status | |
| Skills | Through PN* | n.a. | Through PN & SN* | |
| Personal networks | Migration & socialshifting | Socialshifting | Socialshifting | |
| **Adoption** | | | Mobiles | Internet |
| Main factors | Literacy Income Access | Phones: personal networks Cars: income | Affordability | PNs, SN Digital literacy |
| **Use** | | | | |
| Communication effects | | | | |
| Social solidarity? | Yes | Yes | Yes | Yes |
| Communication substitution? | No | Yes | Yes | Yes |
| New practices? | Yes | No | Yes | Yes |
| 'Global village': | | | | |
| - maintain contact? | Yes | Yes | Yes | Yes |
| - new friends? | No | No | No | Yes |
| Travel effects | | | | |
| Complementary increase? | Yes | Yes | Yes | Yes |
| Travel communications? | Yes | Yes | Yes | Yes |
| Substitution reduction? | No | Yes | Yes | Yes |

PN = personal network; SN = social network

The aim of this thesis was to identify the important factors underlying the relationship between communications and travel, to get a better understanding of why they have grown together, and to address the question 'why are communication and travel complements, not substitutes?'

The key finding is that the growth in demand for communications can be replicated by modelling social interactions. This reflects the fact that the demand for communications and travel are related in that both are generated from social networks. The growth in real income enabled the growth in communications and travel for social reasons, but did not cause it. More specifically:

- the apparent role of literacy in generating rail travel was an unexpected outcome of the modelling;

- there are surprising similarities between the experience with mail in the nineteenth century and with digital communications in the twenty-first. Both rely on the spread of skills – literacy in the nineteenth century and digital literacy in the twenty-first – and both extended personal networks. The impact of the extension of personal networks on travel could be readily seen in the nineteenth century and suggests a similar effect could be occurring in the twenty-first (Chapters 6 and 8);

- the network effect – the fact that there is little point having a phone unless your friends and family also have phones – was more important in the diffusion of phones in the second half of the twentieth century than affordability (Chapter 7);

- the same model, with different parameter values, can reproduce the adoption and use of both mobile and internet communications, underlining the similarities in the dynamic processes underlying both modes of digital communications (Chapter 8);

- some forms of internet communications differ from all previous modes of communication in that they readily allow people to make new contacts rather than simply reinforcing existing links (Chapter 8).

## *9.3 General Implications*

The digital communication revolution is growing out of the social and technological development of mail and phones. Technologically, mobiles can be used to communicate with fixed line phones and nineteenth century fixed line phones are still providing the basis for access to the internet in the twenty-first. Mail and phones both brought about important changes in society: digital communications are doing and will continue to do the same. What might those be?

Schumpeter (1934/1961, p.64) pointed out that no matter how many more horse-drawn coaches were built they would never constitute a railway. The railways represented a step-change, a discontinuity that he labelled "economic development" to distinguish it from "economic growth", which was the result of continuous change (Schumpeter, 1934/1961, pp.63-66). The railway "accelerated and enlarged the scale of previous human functions, creating totally new kinds of cities and new kinds of work and leisure" (McLuhan, 1964/2003, p.20). Cars generated another set of fundamental changes (see, for example, McLuhan (1964/2003, p.294) and Urry (2004b). Digital communications technology is bringing about another round of changes.

By the late 1980s, Simon (1987) suggested that computers were creating the second industrial revolution, although at that time this revolution largely affected organisations rather than homes (Brynin & Kraut, 2006, p.4). Simon (1987) noted that the first revolution, steam, took around 150 years, or six generations. He suggested that the mid-1980s were "the adolescence" of the third generation of this second revolution. He argued that, like the first industrial revolution, the path of the second would be unpredictable and would bring about changes that could not be imagined at its start. Yet by 1990 economists were puzzling over the "productivity paradox", "the apparent failure of the wave of innovations based on the microprocessor and the memory chip to elicit a surge of growth in productivity in the U.S. economy" (David, 1990). Drawing on historical analogy, David (1990) argued that this was because the productivity statistics were not picking up changes such as better quality, and that there were lags in an impact being

observed due to the "gradual and protracted process of diffusion into widespread use, the confluence with other streams of technological innovation, all of which are interdependent features of a dynamic process". David was right. The resulting changes, such as just-in-time production and consumers' access to online marketplaces, have now transformed some aspects of economic life (Greenspan, 2008, pp.168-9). By the early twenty-first century, the impact could be seen: Stiroh (2002) found that "IT-producing and IT-using industries account for all the productivity growth" in the United States since 1995. By 2005, the impact of computers and, more importantly, the internet, was having a measurable impact on UK productivity too (ONS, 2005c). Mobiles also have an economic consequence: it has been suggested that Indian states with high mobile penetration grow faster economically than those with lower penetration (Vodafone, 2009, p.1).

Could the same be happening with social practices, with society changing in ways that we do not yet even realise, and cannot foresee? Collins (1981) suggested that "new communication media" increase the size of group coalitions that can be formed thus bringing about "large scale changes in social structure". Batty (1997) suggested that the subject matter of human geography would be very different in "an age where the digital permeates all human activity". Brynin & Kraut (2006, pp.4 & 6) argued that the internet "could lead to changes in the lives of the average citizen as profound as those that have affected organizations and economic life". It can be argued that the economy involves processes that are more susceptible to change as a result of computers and that the effect on social processes will be much less dramatic. Shklovski et al (2006, p.262) argued that "how people use major blocks of time, their closest relationships, and their emotional lives" resist change and thus impact of these new technologies "may be small, or may be slow emerging".

A majority of experts expect that people will spend part of their lives in types of virtual reality by 2020 (Anderson & Rainie, 2008, p.5). The forecasts presented in Chapter 8 suggest that the internet will be important for creating and maintaining personal networks, but it is only too likely that there will be important effects which we cannot at

present foresee. The distinction made by economists between the short term and the long term is useful here. In the short term, a new mode of communication is simply used to do whatever people did previously but in a new way. In the long term, everything can change. Root (2000, p.452) argued that predicting the impact of current developments "is like trying to forecast the effects of mass car ownership in 1908 when the first Ford model T cars were made". Kraut et al (2006) argued that "the dramatic changes now occurring in household computing have the potential to change the lives of average citizens as much as the telephone did in the early 1900s in the US". Indeed, Urry (2004b) suggested that there will be a dramatic changes in many aspects as rich societies abandon the car during the course of the twenty-first century and replace some face-to-face encounters with simulations, but so far, there has been little sign of such changes.

Harper (2003) argued that mobiles have increased social solidarity. Indeed, there is some suggestion that there could be too much contact, as noted by Cooper (2002, p.27) and more recently, by Turkle (2008) who talked of 'tethering'. Koskinen (2008) talked about people becoming disengaged from those around them, focusing on their own small group. This constant connectivity provided by mobiles led Clarke (2003, p.27) to suggest that mobiles represent "entry level cyborg technology". More prosaically, there is evidence of increasing dependency. For example, in 2005, *The Times* reported a mountain rescue team complaining that mobiles had created climbers who no longer saw the need to go out properly equipped because "help is just a phone call away" (Midgley, 2005). This is a form of moral hazard, taking additional risks because you know that you are in a sense 'insured'. But perhaps it goes further: McLuhan & Powers' (1989, p.129) warned that the faster information is exchanged "the more likely we will all merge into a new robotic corporate identity" and, more recently, Rheingold (2002, pp.201-2 & 208-15) warned of the dangers of cyborgism while at the same time pointing to the advantages that new forms of social co-operation can bring.

The Introduction mentioned the argument about social solidarity and the fear that new communication technologies, especially the latest digital wave, were in some sense 'bad' for society. Yet the story told here is one of technology permitting more contact between

more people: more communication and more travel. The recent development of social networking websites such as *Facebook* brings together different social circles, allowing them to overlap in a way not previously seen.

Overall then, social solidarity is being increased, not reduced. Long ago McLuhan, (1964/2003, p.19) argued that "the 'message' of any medium is the change of scale or pace or pattern that it introduces into human affairs" "because it is the medium that shapes and controls the scale and form of human association and action" (where a medium was defined as "any extension of ourselves", "any new technology") (McLuhan, 1964/2003, pp.19-20). We do not yet understand the "message" of this digital revolution although many scenarios have been offered (for example, Rheingold, 2002, pp.183-202; Brynin & Kraut, 2006, p.3; Foresight, 2006b; Urry 2007, pp.271-290). Thus it may be that social changes will take longer to appear than the economic changes and are not yet evident. More broadly, I suggest that sociologists in 2010 are in much the same position that economists were in 1990, knowing great changes are underway but not yet able to identify them.

## *9.4 Policy Implications*

Three policy implications arise from this research. The most important result is that the Government is very unlikely to be able to rely on the digital revolution to reduce the demand for travel. The Government should also:

- give greater weight in its transport policy decisions to social needs that are met by travel;
- expect the digital divide to persist for many years and plan its services accordingly.

## Impact of the digital revolution on travel

No evidence has been found to support the idea that in social life, communications reduce travel. Indeed, all the evidence points in the opposite direction; and in particular, it appears that the digital revolution is unlikely to reduce the demand for travel. There is increasing evidence that cheap, accessible long-distance digital communications will increase rather than reduce travel by enabling people to create and maintain geographically-widespread personal networks. Yet this factor is not even mentioned in the CAA's (2009) recent report on travel to visit friends and relatives.

If it is seen as desirable to reduce travel then policy makers need to exploit the facts that travel is, and will continue to be, constrained by time and money. To reduce demand, travel will need to be more expensive and slower. Demand for travel is fairly insensitive to price, at least in the short run (as discussed in Chapter 2), so large price increases would be needed to reduce travel demand. There appears to be a limit to the amount of time people will spend travelling. Thus the recent announcement of tighter speed limits, albeit for safety reasons (BBC, 2009a), may therefore reduce travel by increasing journey times. And of course, there is a natural negative feedback mechanism in that congestion increases travel time. But any action to reduce travel will be in direct conflict with that to better meet social needs as discussed below, a conflict to be recognised and resolved.

## Social needs

Before the universal Penny Post, there was basically a choice between mobility and keeping in contact with friends and relatives: if you moved away, you lost contact (Chapter 6). Subsequently it has been increasingly possible to have both. The desire for both underlines the complementary relationship between communications and travel. Thus communication reduces social costs of travel in that you can travel and still keep in touch. The fact that households bought cars in preference to phones up until the mid-1970s (Chapter 7) suggests that face-to-face contact is preferred where possible to voice-only contact. Maintaining contact is made even easier and cheaper by the digital revolution; email and social network sites, for instance, enable people to keep in touch with their friends and relatives thousands of miles away in a manner that would have been unachievable twenty years ago due to time taken by letters, the costs of international calls and the practicalities of synchronous communication across time zones.

Parts of British society have been geographically mobile for centuries (Chapter 6) and it can be argued that this mobility has facilitated, perhaps even caused, the country's economic development (for example, Macfarlane, 1978). Yet social ties are important economically: they facilitated job search both in the nineteenth century (Chapter 6) and more recently (Granovetter, 1973). So while geographical mobility brings economic benefits, it also imposes social costs, by disrupting personal networks. Much rail travel was originally for social purposes and cars were initially bought for social use rather than commuting. Yet the Government tends to dismiss social needs, placing a lower value in economic appraisals on the time taken for leisure travel. Although the social need is recognised in terms of removing road works on Bank Holiday weekends, the opposite appears to happen on public transport. For example services are often reduced at weekends and Bank Holidays or, on the railways, even suspended completely for maintenance (Pank, 2009). There is often a complete shut down of the UK network for several days over Christmas. If social travel is indeed important to both the economic performance and social cohesion of the country, then it should be given a higher place in the Government's priorities.

## The Digital Divide

The digital divide is not likely to disappear quickly. The Government must take into account that there are significant minorities who do not live in this digital world and that these minorities may persist for some decades. The models in Chapters 6 and 7 both showed that even after decades there still remained groups that were in a sense unconnected. As described in Chapter 8, there is a significant minority who have not joined the digital revolution due to lack of skills, resources or interest. Although reducing in size, this minority will persist for many years yet, particularly among the very elderly, who are a fast growing segment of the population.

Helsper (2008, pp.57-58) drew attention to the fact that electronic services may not be accessible to those who need them most. As travel information and payment methods are increasingly provided electronically, (see for example, BBC (2009b) and Urry (2004b)) those who are not online or using the more advanced features of mobiles are increasingly excluded. Yet such people are likely to be those who are least able to afford alternatives and who most need to use public transport. The Public Accounts Committee (PAC) has recently complained that low cost rail fares are available only to those with internet access (PAC, 2009). The Government acknowledges that "we are at a tipping point in relation to the online world. It is moving from conferring advantage on those who are in it to conferring active disadvantage on those who are without" (BIS, 2009, p.11). The Government is committed to developing the internet as the primary means of accessing services, albeit with a "safety net" for those not online (BIS, 2009, p.210). Creating that safety net is the real challenge.

## *9.5 Lessons for Methodology*

I suggest that this thesis has demonstrated the usefulness of modelling in the sense of the definition of a model offered in Chapter 1 i.e. explicit, quantifiable statements that describe a process. A wide range of social, economic and demographic data was brought together to draw pictures of what might have happened during the three periods studied. With this data, but without the modelling, it would have been possible to make a qualitative assessment of the factors underlying the observed growth in communications and transport along the following lines:

- In the nineteenth century, migration, income growth, increasing literacy and the expansion of the railways resulted in the observed growth in demand for mail and rail services.

- In the twentieth century, income growth and demographic changes underpinned the growth in adoption of phones and cars.

- At the start of the twenty-first century, the new digital communications is beginning to transform the social landscape for those who can afford them and have the skills to use them.

By combining data from qualitative and quantitative studies, using concepts from both sociology and economics, modelling made it possible to say more: to assess the relative importance of each of these factors and, more importantly, to demonstrate the central role played by personal networks and the importance of skills. Furthermore, without the modelling, it would not be possible to make quantitative forecasts. Society is a complex system and in complex systems, dynamic, non-linear interactions between many factors produce the observed outcome (Chapter 1). Verbal analysis alone cannot deal with this complexity. Both verbal analysis and modelling are essential components in the iterative process of the scientific analysis of social phenomena.

The three case studies also demonstrate the usefulness of models that fall between detailed evidence-based models and more general, abstract models; but they also show the difficulties of creating descriptive models. Two particular problems emerged: modelling household formation and generating income distributions. The modelling in

Chapter 7 demonstrated how difficult it is to model household formation dynamics: much detailed work was needed to reproduce observed trends. For income distribution, two methods were used:

- a bottom-up approach, working from the characteristics of the agents to generate an appropriate Gini coefficient, the standard measure of income inequality (as done in Chapters 7 and 8);
- a top down approach, starting with the Gini coefficient (as described in Chapter 6), an approach which is useful when little data is available.

If descriptive models are to be used, work needs to be done on producing these basic building blocks of agent-based models.

Gilbert (2006) identified four "difficult" areas to be addressed in the future development of agent-based modelling: social networks, innovation, culture and history. What does this thesis offer in these areas?

- Gilbert complained that in social simulations, the maintenance of social networks was assumed to be costless. The new social circles model presented here (Chapter 4) limits the size of personal networks in recognition of the maintenance costs.
- Although the thesis looked at the adoption of technology, the agents did not themselves innovate.
- Culture was implicit. For instance, in the phone-car and mobile-internet models (Chapters 7 and 8), the middle-upper class are assumed to be geographically mobile and this mobility is assumed to underlie their demand for communications.
- Gilbert argued that the current state of the real world depends almost entirely on its past; however, in social simulations, runs usually start with a uniform random initial state. To add history means assumptions have to be made, for example about agents' literacy in the nineteenth century model and about the pattern of phone adoption in 1951 in the twentieth century model. This problem was partly addressed in that in two models by undertaking very long time runs, of up to 70 years. Such long periods allowed agents to generate their own history: in the nineteenth century model (Chapter 6) 99 percent of original agents had 'died' and been replaced by the end of the 70 year period, while in the twentieth century

model (Chapter 7), 94 percent of the households had been replaced by the end of the 50 years modelled.

To sum up, I suggest that in addition to demonstrating the value of modelling, this thesis offers three important lessons:

- the importance of looking at dynamics;
- the importance of looking at the long run;
- the importance of a multidisciplinary approach.

## *9.6 Further Work*

There are at least five basic strands of further work:

- To investigate the apparent paradox between the constancy of time spent travelling at the aggregate level with variations at the individual level using agent-based modelling (Chapter 2).

- To explore further the properties of the social network model based on social circles (Chapter 4).

- To explore the agent-based modelling of households and thus the relationship between individuals and households. The modelling of household formation, especially in the late twentieth century, could be a major project in its own right (Chapter 7).

- To develop further the analysis of communication and travel in the digital age (Chapter 8), such as the relationships between youth, mobility and maintaining links over distance, between different types of 'e-friends' and between weak and strong links.

- To develop different kinds of agent-based models to investigate the relationship between social and communication networks at a more abstract level, and to allow more interaction between agents.