Communications, Travel and Social Networks since 1840: A Study Using Agent-based Models

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Abstract

This thesis investigates the dynamics of the relationship between personal communications and travel, using agent-based computer simulation modelling. It focuses on the interaction between social, communication and transport networks. The novelty of the thesis lies in using this new modelling technique to identify the important factors underlying this relationship, to get a better understanding of why communication and travel have grown together, and to address the question ‘Why are communication and travel complements, not substitutes?’

A new way of modelling social networks is presented, based on social circles, which reflects the characteristics of social networks better than the standard network models. This social network model is then used as the basis for three case studies, drawing on qualitative and quantitative secondary data. The first case study looks at the development of mail from 1840 to the start of the First World War; the second at fixed-line phones from 1951 to 2001; and the third at mobile communications and the internet from 1998 to 2007, with forecasts to 2021.

The key conclusion is that communication networks evolve out of social networks as does travel for social purposes. When a new communications technology is introduced, affordability is always an initial constraint on take-up, but in the nineteenth century literacy was also important, as is ‘digital literacy’ in the late twentieth and early twenty-first centuries. Literacy enables people to keep in touch with those who are geographically remote and this communication is likely to engender travel. Because the internet facilitates meeting new people, this effect is strengthened in contrast to earlier communication modes which have in general only facilitated contact between people who are already known to one another.

Contents

Declaration of Originality

"This thesis and the work to which it refers are the results of my own efforts. Any ideas, data, images or text resulting from the work of others (whether published or unpublished) are fully identified as such within the work and attributed to their originator in the text, bibliography or in footnotes. This thesis has not been submitted in whole or in part for any other academic degree or professional qualification. I agree that the University has the right to submit my work to the plagiarism detection service TurnitinUK for originality checks. Whether or not drafts have been so-assessed, the University reserves the right to require an electronic version of the final document (as submitted) for assessment as above."

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Introduction

This Introduction starts by explaining in Section 1 the general issues to be addressed. Section 2 sets out the scope and Section 3, the basic methodology. Finally, Section 4 outlines the structure of the thesis.

1. The Issues

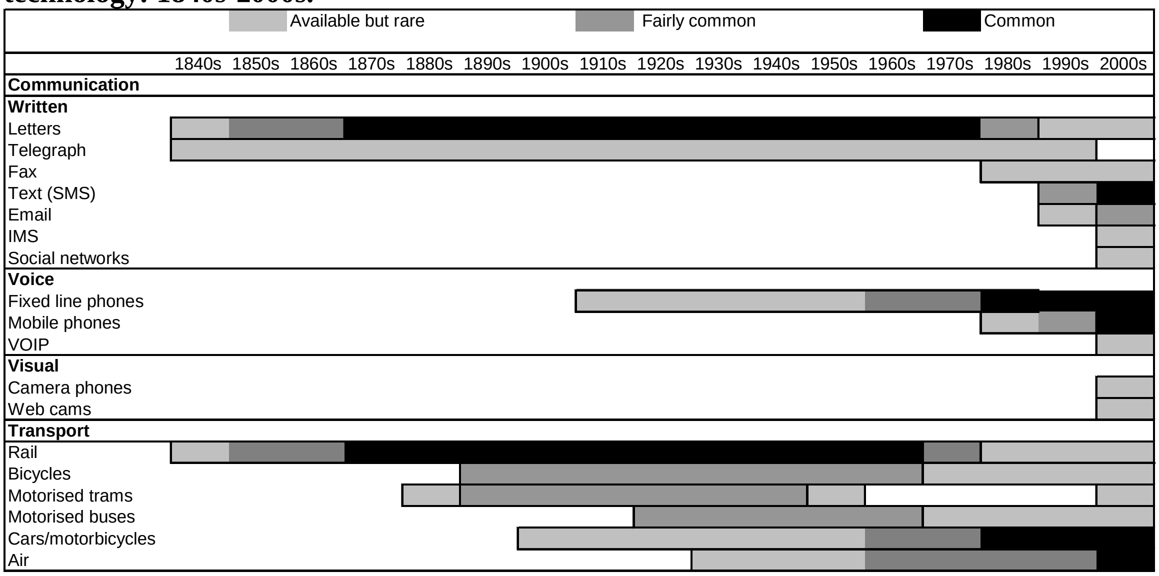
Communications and transport networks were once regarded as synonymous because the postal service enables communication through transport networks. The two started to diverge with the arrival of optical telegraphy in the 1790s and then electrical telegraphy in the 1840s (Headrick, 2000, p.193; Ling & Yttri, 2002; Sterne, 2006, p.119). This thesis follows the Oxford Dictionary (2001) definitions: communications refer to the movement of information, and transport refers to the movement of people.

Communication and travel have grown in parallel. Although a postal service existed in Britain in Roman times (British Museum, 2009), the introduction of the universal Penny Post in 1840 marked an important development. Trevelyan (1937/1962, p.278) asserted that “for the first time in the history of man” “the poor” were able “to communicate with the loved ones from whom they were separated”. As noted, the electric telegraph arrived at about the same time. Then came telephones, fixed line in 1879 and about a hundred years later, mobiles. By the early years of the twenty-first century, we were talking on phones for 250 billion minutes a year and sending 80 billion text messages (Chapter 8). And there is now the internet, the effects of which we are just starting to see.

Yet we travel too. In 1835, people on average made 0.6 journeys a year by stage coach (Chapter 6). The railways replaced stage coaches and made travel possible to an unprecedented extent. Now we make over 1,000 trips a year, totalling over 7,000 miles, and about double the mileage travelled even 40 years ago. In addition and we make some

70 million trips abroad each year (Department for Transport (DfT), 2008; Eddington, 2006, Vol 2, para 1.1; Root, 2000, p.463). The technological innovations in both communications and transport since the 1840s and their popularity are outlined in Fig. 1.

Fig. 1: Indicative timeline of the availability and use of personal communications and travel technology: 1840s-2000s.



Now economists say, glibly, that the growth in demand for communications and travel is obviously due to economic growth: as people become better off they can afford to communicate and travel more. However, while economic growth provides the means, it does not explain why people choose to spend their rising real incomes on communications and travel. When the Post Office was opposing Rowland-Hill's Penny Post proposal in the late 1830s, they asked "Why should people want to send letters just because it's cheap to do so?" (Daunton, 1985, p.22). In economists' language, communications and travel appear to be complements rather than substitutes. The aim of this thesis is 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?"

Why study this question?

The relationship between new communication technologies and travel is of interest within academia and to policy makers. Firstly and obviously, it is relevant to the concern about the environmental impact of travel. Secondly, it is relevant to the long-running debate about the impact of technology on society, in particular on social solidarity. The rest of this Section provides a brief overview of these two themes.

Economic and Environmental Costs of Travel

The Government's policy, set out in *The Future of Transport White Paper* (DfT, 2004) is to "manage the growing demand for transport" rather than "simply providing ever more capacity on our roads and railways, ports and airports" because "the damage to our environment, landscape, towns and cities and our quality of life would be unacceptable" (DfT, 2004, para 8). The future development of travel and transport networks is controversial, and in 2006 three major official reports appeared:

- The Office of Science and Technology's (OST) Foresight *Intelligent Infrastructure Report* which looked at how science and technology could be used over the next 50 years to create "robust, sustainable and safe transport, and its alternatives" (Foresight, 2006a, pp.16, 18);
- The *Eddington Transport Study*, commissioned by the Treasury and the DfT which looked at transport's "long-term impact on the UK's economic growth, productivity and stability, within a sustainable development context" (Eddington, 2006);
- The Stern Review (2006), *Report on the Economics of Climate Change*, "an independent Review" commissioned by the Chancellor of the Exchequer.

More recently, in July 2009 the Government published *Low Carbon Transport, a Greener Future*, which set out its strategy to reduce carbon emissions from transport while not reducing the quality of life (DfT, 2009, pp.3-4).

The UK’s roads are the most congested in Europe (Root, 2000, p.451; Foresight, 2006a, p16). The cost of congestion is usually measured in terms of time wasted by business and freight traffic. On this basis congestion is estimated to cost the UK economy some £7-8 billion per annum (in 2005 prices), which is about the same as is currently spent each year to “maintain and develop transport infrastructure” (Eddington, 2006, Vol 1, p.12; Foresight, 2006a, p.2). But even though leisure trips “dominate the demand for travel after standard working hours on weekdays”, they are not included in congestion costs because their “impact on other travellers is minimal” (Eddington, 2006, Vol 2, para 1.53).

Even when leisure time is taken into account in the DfT’s economic appraisals, it is valued significantly less than work time: at around £5 an hour – about the same as the minimum wage – compared to £20 to £45 an hour for work time (in 2002 prices) (DfT, 2007a). Work time is valued so highly because it includes the value to the business and the low valuation of leisure time is based on people’s “willingness to trade time for money” (ibid). While DfT’s assumptions seem to be at odds with the often-expressed view that we live in a time-poor money-rich society it is argued that time-pressure has only affected certain groups (Gershuny, 2000, pp.46-75). And despite the growth in trips and distance travelled, “the time spent each day on regular travel activity has remained constant at an average of 1½ hours” (Foresight, 2006b, p.21). Time use is discussed in Chapter 2.

Furthermore, the DfT’s position underlined Larsen et al’s (2006, p.153) point that “policy discussion of leisure travel has often adopted a language which questions the necessity of such travel”. Larsen et al argued that rather than being unnecessary, this travel is “essential” to maintain society’s “social capital”, such as social networks (Coulthard et al, 2002, p.x). If the importance of this travel were recognised, Larsen et al argued, it would have implications for the provision of public transport, for example at weekends (2006, p158). The Stern Review (2006, Annex 7.c) noted that “the welfare costs of reducing demand for travel are high” and it is presumably at least partly in recognition of this high cost that current transport policy seems to assume that environmental targets can be met largely by "decarbonising transport" through the application of new technology (DfT, 2009, p.5) rather than reducing the demand for travel.

Social Solidarity

The impact of new technology on the cohesion of society has always been a central concern of sociology. For example, Marx and Durkheim both looked, in different ways, at the impact of the industrial revolution on social cohesion and "Few ideas saturate Western thought as does the conviction that modern life has destroyed 'communities'…" (Fischer, 1982, p.1). Policy makers share this concern: the Foresight report talked of the need for strategies to "enhance social cohesion" (2006a, p.11).

Tönnies (1887/1957) introduced the idea that there has been a change from "gemeinschaft" – the pre-industrial world of villages, with close, face-to-face ties, where people are fixed geographically and socially in a homogeneous and regulated community – to "gesellschaft" – the urban, industrial world, in which people are mobile in heterogeneous and impersonal communities. Whether the world was ever as described by gemeinschaft or that the modern world is accurately described by gesellschaft is debateable. Even more debateable is the underlying value judgement that gemeinschaft is good and gesellschaft, bad.

Kranzberg's First Law says that "Technology is neither good nor bad, nor is it neutral", because of long-term unforeseen consequences or its use in different contexts, often arising as a result of widespread use (Kranzberg, 1986). Root (2000, p.463) commented that more communication and travel have created "opportunities and pleasures" while "causing environmental damage and reducing quality of life in ways that we have not sought". Technology brings about changes, for the better for some people, at least some of the time, but maybe not for others. How to weigh the benefits to some against the costs to others is the basic problem of welfare economics: the extreme view, defined by Pareto, is that a change can only be said to be for the better if no one is made worse off (*Oxford Dictionary of Philosophy*, 1996, p.277).

Whether any given technological development is good or bad for an individual or for society is a matter of judgement, but in order to make such a judgement, the effects must first be identified and quantified. Castells (2000, p.357) said:

> “Fortunately while there is technological discontinuity there is in history a great deal of social continuity that allows analysis of tendencies on the basis of the observation of trends that have prepared the formation of the new system over the past two decades”.

Technological discontinuities are imposed on social continuity, but ‘social continuity’ should be looked at over many decades, if not centuries. I hope this thesis may be seen as a contribution to a better understanding of those processes and their effects.

2. The Scope

Communication and travel are very wide topics. To make the project manageable, I focus on person-to-person social communication that is mediated through a communications network (such as the postal service or email) or involves a journey, which could be regarded as mediated through the transport network. By social communication, I mean interaction with friends and family; something close to Habermas's concept of 'lifeworld'. A key determinant of an individual's demand for social communication and travel will therefore be the number and strength of links with other people: in other words, their social network (Foresight, 2006a, p.21; Larsen et al, 2006). Thus this project investigates the relationship between social, communication and transport networks.

Narrowing the topic means that certain areas of communication and travel will not be covered, in particular:

- confining the project to person-to-person communication excludes broadcasting, sending information from one to many. This clearly rules out television and radio as well as RSS feeds and information web sites. Thus travel generated by seeing places on TV or on the internet is not covered.
- confining the project to social communication excludes business communications, which depend on the size and character of organisations and management practices rather than on personal preferences and social networks. This study does not cover home-working versus commuting, which arises from the interaction between individuals' decisions on labour supply and geographical location and the impact of the industrial structure and planning system. Nor does it cover the choice between internet shopping and High Street shopping.

3. The Approach

> "The Method I take…is not very usual; for instead of using only comparative and superlative Words, and intellectual Arguments, I have taken the course … to express myself in terms of Number, Weight or Measure; to use only Arguments of sense, and to consider only such Causes, as have visible Foundations in Nature; leaving those that depend on the mutable Minds, Opinions, Appetites and Passions of particular Men" (Petty, *Political Arithmetic*, 1690 as cited in Headrick, 2000, p.62)

Following Petty, I use a quantitative approach. Specifically, I have chosen to use modelling, the benefits of which are discussed in Chapter 1. In particular, I use agent-based computer simulation modelling, also called multi-agent based simulation, to create artificial societies (Epstein, 2006, p.xii). Agent-based modelling has been developed since the early 1990s (Gilbert, 2007, p.5).

Search of the *Journal of Artificial Societies and Social Simulation* (JASSS) and an enquiry in February 2007 on the SIMSOC list (http://www.jiscmail.ac.uk/lists/simsoc.html), the key discussion list for "news and discussion about computer simulation in the social sciences", suggested that this technique has not previously been used to investigate the relationship between communications and travel.

4. Outline of the Thesis

This project investigates the dynamics of the relationship between personal communications and travel, using agent-based computer simulation modelling. It focuses on the interaction between social, communication and transport networks. It is hoped that the thesis will contribute to the development of modelling techniques, to the current economic and environmental debate about transport and to the sociological debate about the effect of new technology on society. The novelty of the project lies in using agent-based modelling, a new technique, to identify the important factors underlying this relationship, to get a better understanding of why communication and travel have grown together, and to address the question "Why are communication and travel complements, not substitutes?"

The presentation of this thesis is somewhat unconventional because it uses a new methodology and because it is so wide-ranging:

- As Gilbert & Troitzsch (2005, p.26) noted, there is "a tension" to be resolved in reporting social simulation modelling, between explaining the social science without too much technical detail while at the same time providing enough information for the modelling to be replicated, replication being essential scientific practice. It would therefore not be appropriate to simply relegate the technical material to an annex; it is an essential part of the thesis. To address this problem, the technical issues are confined to boxes in the main text.
- There is no chapter called 'literature review' because almost every chapter includes a review of relevant literature: for example, the literature on social networks is covered in Chapter 3 while that on the use of mobiles is covered in Chapter 8.

The first two chapters set the general scene:

- Chapter 1, *Theory and Methodology*, briefly reviews theory about the relationship between society and individuals. It then justifies the use of modelling in general, and introduces agent-based modelling.
- Chapter 2, *Time and Money*, sets out the long term trends in time use and in the consumption of communications and travel.

The next two chapters deal with networks:

- Chapter 3, *Networks*, discusses the characteristics of and relationship between social, communication and transport networks and their modelling.
- Chapter 4, *A New Model of Social Networks*, presents a new approach to generating social networks in agent-based models.

Then:

- Chapter 5, *A General Model*, presents a general model of communication and travel that underlies the case studies.

Three long chapters describe the three case studies:

- Chapter 6, *Mail and Rail*, explores what happened following the introduction of the universal Penny Post and the railways, focusing on 1840 to 1913.
- Chapter 7, *Phones and Cars*, looks at the relationship between fixed-line phones and cars, from 1951 to 2001.
- Chapter 8, *Mobiles and the Internet*, draws on the previous Chapters to develop a model of digital communications from 1998 to 2021.

Finally, Chapter 9 concludes by summarising the thesis, discussing the relationship between communications and travel, setting out policy implications, discussing methodological lessons and indicating directions for further work.

A list of acronyms and a glossary are also provided.

Chapter 1: Theory and Methodology

This Chapter starts by summarising the sociological theory of the relationship between individuals and society in Section 1. Section 2 explains what is meant by a model and discusses the benefits of modelling. Section 3 describes the different types of modelling techniques available and explains why agent-based modelling is used in this thesis. Section 4 reviews agent-based modelling of transport and communications. Section 5 justifies the type of agent-based modelling used in this thesis and Section 6 explains how agent-based models work, and how they are designed and tested. Section 7 summarises and concludes.

1.1 The Individual, Society and Emergence

According to Elias (1970/1978, p.129) the individual and society are “two different but inseparable levels of the human world”. A key debate within sociology concerns the relationship between the individual and society: does society have properties that are not just the sum of individuals or their actions i.e. is there is emergence? However, the term ‘emergence’ has been used in many ways (Sawyer, 2005, p.3; Cederman, 2005; Epstein, 2006, p.31), and so it is important to start by clarifying the terminology. It is generally recognised that J.S. Mill first identified emergence in his *Logic*, published in 1843, although he did not use that label. Given this, together with the clarity with which he expresses the ideas, I make no apology for setting out his position at some length.

Borrowing from mechanics, Mill (1843/1973, Book III, Ch VI, pp.370-371) identified what he called “the Composition of Causes” in which:

> “one cause never, properly speaking, defeats or frustrates another; both have their full effect. If a body is propelled in two directions by two forces, one tending to drive it to the north and the other to the east, it is caused to move in a given time exactly as far in both directions as the two forces would separately have carried it; and is left precisely where it would have arrived if it had been acted upon first by one of the two forces, and afterwards by the other”

Thus for "mechanical" causation, Mill said:

> "we can compute the effects of combinations of causes, whether real or hypothetical, from the laws which we know to govern those causes when acting separately; because they continue to observe the same laws when in combination which they observed when separate" (Mill, 1843/1973, Book III, Ch VI, pp.370-371).

Modern writers have invented their own terminology for this process. For example Smith (1997, p.58) used the term "aggregative" while Cilliers (2000) talked about complicated processes which can have many stages but the relationships between them are fixed and can be defined by rules. In modern parlance, Mill's mechanical process can be described as reductionist, because the whole can be reduced to a set of components.

In contrast, "chemical" reactions, Mill suggested, operate differently:

> "The chemical combination of two substances produces, as it is well known, a third substance with properties different from those of either of the two substances separately, or of both of them taken together" (Mill, 1843/1973, Book III, Ch VI, pp.370-371).

This "chemical combination" can be described as emergence.

In conclusion:

> "This difference between the case in which the joint effect of causes is the sum of their separate effects, and the case in which it is heterogeneous to them; between laws which work together without alteration, and laws which, when called upon to work together, cease and give place to others; is one of the fundamental distinctions of nature" (ibid, p.373).

During the 1920s, emergence was used to describe phenomena that were unexplainable in that the characteristic properties of the whole could not be deduced from the "most complete knowledge" of the properties of the components (Epstein, 2006, p.32). The concept of emergence is now intimately connected with the idea of non-linear, dynamic, complex systems:

> "constituted through a large number of dynamic, non-linear interactions…Living things, language, cultural, and social systems are all complex… complex things have emergent properties" (Cilliers, 2000).

Strogatz (1994, pp.8-9) explained:

> "…linear systems can be broken down into parts. Then each part can be solved separately and finally recombined to get the answer. But many things in nature don't act in this way. Whenever parts of a system interfere, or cooperate, or compete, there are nonlinear interactions going on. Most of everyday life is nonlinear."

It is therefore essential to be able to look at the system as a whole as well as the individual components, the macro as well as the micro. As Bak (1996, p.60) observed, if faced with a "complex, critical system" i.e. a large system in which minor changes may have major consequences (ibid, pp.1-2) then "studying individual grains under the microscope doesn't give you a clue as to what is going on in the whole sandpile." The idea is that if you pour grains of sand into a pyramidal pile, as the pile grows landslides will occur. These landslides are unpredictable and can be very large. This sort of effect is thought to underlie stock market crashes (Gilbert & Troitzsch, 2005, p.10).

How do these concepts apply to society? Mill was quite clear that the chemical mode did not apply to society: in *Logic* (1843/1974, Book VI, Ch VII p.878) he wrote:

> "The laws of the phenomena of society are, and can be, nothing but the laws of the actions and passions of human beings, united together in the social state. Men, however, in a state of society, are still men; their actions and passions are obedient to the laws of human nature. Men are not, when brought together, converted into another kind of substance, with different properties; as hydrogen and oxygen are different from water…Human beings in society have no properties but those which are derived from, and may be resolved into, the laws of the nature of individual man. In social phenomena the Composition of Causes is the universal law".

This view, that society is the 'simple' sum of its parts, is echoed today by symbolic interactionists such as Goffman (1983, p.6) who argued that most of the rules framing society are created and maintained "from below".

Durkheim was the first sociologist to talk about emergence, although he did not use the term (see for example, Sawyer, 2005, pp.100-108). Durkheim's sui generis argument is essentially that the interactions of people create society but that society in turn shapes them:

> "Because individuals form a society, new phenomena occur whose cause is association, and which, reacting upon the consciousness of individuals, for the most part shapes them. That is why, although society is nothing without individuals, each one of them is much more a product of society than he is the author" (Durkheim, 1893/1984, p.288).

Simmel saw society not as a "'substance,' nothing concrete, but an event" in which "languages, social structures, norms, and conventions are created through 'societal production, according to which all these phenomena emerge in interactions among men'" (cited by Cederman, 2005).

In the 1960s Coleman noted that by observing the interactions of many gas molecules, scientists derived Boyle's Law, which describes aggregate behaviour, and reasoned that social scientists could do the same, moving from individual behaviour to group behaviour (Smith, 1997, p.52). Coleman argued that "the proposition system begins and ends at the macro level, but in between it dips to the level of the individual" (Coleman, 1994, p.8) which is the only place that action can occur because:

> "the system level exists solely as emergent properties characterizing the system of action as a whole. It is only in this sense that there is behavior of the system. Nevertheless, system-level properties will result, so propositions may be generated at the level of the system" (ibid, p.28).

Coleman identified "three kinds of components to any theory in which system behavior derives from actions of actors who are elements of the system" (ibid, p.11):

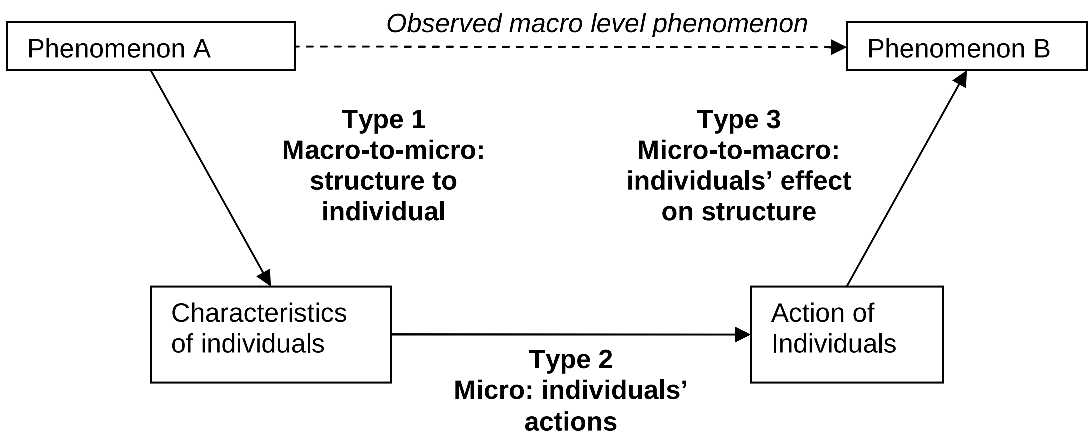
- Type 1: macro-to-micro or structure to individual:

  "the rules of the game, rules which transmit consequences of an individual's action to other individuals and rules which derive macro-level outcomes from combinations of individuals' actions" (ibid, p.19).
- Type 2: micro or individuals' action:

  "gives rise to different systematic behavior – that is, different social phenomena – when located in different social contexts when different persons' actions combine in different ways" (ibid)
- Type 3: micro-to-macro or individuals' effect on structure.

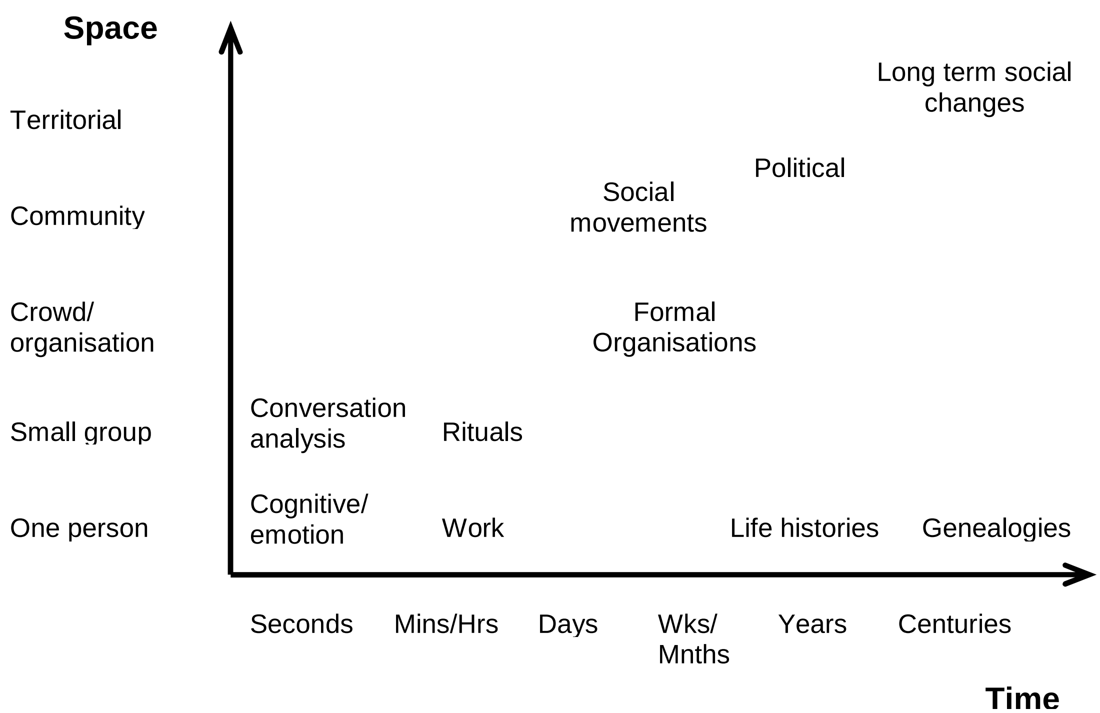
Thus in Coleman's view of the world an apparent relationship between two observed macro level phenomena is underpinned by micro level characteristics and action as illustrated in Fig. 1.1.1 (based on his 1994, p.8, Fig. 1.2). Coleman has, however, been criticised for the fact that the arrows flow in only one direction, not allowing feedback (Ritzer & Goodman, 2004, p.491).

Fig. 1.1.1: Coleman's example of micro-macro interactions.



In contrast Collins (1981) saw the relationship between individuals and society as a continuum in time and space, illustrated in Fig.1.1.2: the time period under consideration varies from seconds to centuries; the space from that occupied by a single individual to a 'territorial society'. The lower and further left in the diagram, the more micro; the higher and further to the right, the more macro. Thus the micro-macro question is how to bring together analysis of activity at the bottom left-hand corner of the diagram with analysis of activity at the top right-hand corner.

Fig. 1.1.2: Summary of Collins' (1981) view of micro-to-macro spectrum.



Collins (1981) proposed linking macro and micro through what came to be labelled as 'situationalism'. Institutions are made up of people so interacting with an institution means interacting with people. Thus "micro levels of interaction are not between individuals as isolated social entities, but between individuals considered as bearers of the affairs of larger social units" so that micro and macro are linked through "interaction ritual chains" (Collins, 1981 & 1987). Collins (1987, p.196) identified the "'mesostructure', the network of repeated encounters". According to Rawls (1992), the idea of a mesostructure fits with "classical sociological theory" which "has from the very beginning...incorporated the notion of a middle level of social connectedness that generates both individuals and institutions".

Habermas, too, acknowledged that interacting with institutions means interacting with people, but built on it differently. He saw “society as a system that has to fulfil conditions for the maintenance of sociocultural lifeworlds” where the lifeworld is “a context forming background of processes of reaching understanding” by communication (Habermas, 1987, pp.126 & 151-2). Essentially, in the lifeworld people interact with people as people, for companionship and emotional support. It is the basis of personal life. This contrasts with interacting with people as representatives of the state and the economy, the ‘system’, when interactions are task-driven and functional (Myerson, 2001 p.30; Edgar, 2006, p.88).

This view provides a vertical hierarchy: micro at the bottom, macro at the top and meso in between. There is, however, another way of looking at the relationship between individuals and society, namely the agency-structure duality that does not imply this vertical structure “since both agency and structure can be found at any level of social analysis” (Ritzer & Goodman, 2004, pp.483-536). An example is Giddens’ theory of “structuration”, a set of conditions that govern “the continuity or transmutation of structures” – rules and resources – “and therefore the reproduction of social systems”, “relations between actors or collectivities, organized as regular social practices” (Giddens 1984, p.25). He saw a duality: “the structural properties of social systems are both medium and outcome of the practices they recursively organize”. Due to the wide scope of his theory and its lack of clarity, not surprisingly Giddens has been widely criticised (for example, by Craib, 1992). Gilbert (1995, p.147) suggested that Giddens was arguing that:

> “human action is both constrained and enabled by social structures, for this is the medium through which action is performed. Structure is at the same time both the outcome of knowledgeable human conduct and the medium that influences how conduct occurs”.

Richmond (1969) introduced the idea of “verbindungsnetzschaft”, a post-industrial society characterised by networks. According to Richmond, in gemeinschaft societies interaction is within communities, communication is mostly oral and transport by horse and sail; and in industrial gesellschaft, interaction is within associations, communication is mostly written and transport steam-propelled. In contrast, in verbindungsnetzschaft societies, interaction is through social networks, communication by electronic means and transport by jet and rocket. Specifically verbindungsnetzschaft societies are characterised by social interaction taking place

> "through networks of communication maintained by means of telephone, teleprinter, television and high speed aircraft and space-craft etc. Such relationships are not dependent on territorial base or face-to-face contact" (Richmond, 1969).

More recently writers such as Castells (2000, pp.500 & 508), Meyrowitz (2004) and Urry (2003a) have taken up this idea. Meyrowitz (2004) argued that as a result of new communications technologies, the social world should be seen as intersecting networks that allow "the possibility of having multiple, multi-layered, fluid, and endlessly adjustable senses of identity. Rather than needing to choose between local, place-defined identities and more distant ones, we can have them all, not just in sequence but in overlapping experiences" (Meyrowitz, 2004). Yet, as Simmel (1922/1955, pp.140-2) argued long ago, an individual's identity is defined by the many different groups to which that individual belongs. Thus Meyrowitz appears to be claiming that this effect is stronger than in times past and not so tied to physical location. Wellman (2000, para 8.3) too saw digital technologies resulting in a fundamental change by enabling connections between people rather than places because in the place-based, gemeinschaft society people interacted with one group at a time whereas in a computer-supported social-networked, gesellschaft society there is much greater scope to move between social circles.

Urry (2003a, p.122) has taken this further, arguing that "there is no 'structure' and no 'agency', no 'macro' and no 'micro' levels, no 'societies' and no 'individuals', and no 'system world' and no 'lifeworld'". Instead, he said, there is "relationality" brought about "through a wide array of networked or circulating relationships that are implicated within different overlapping and increasingly convergent material worlds". There is, he proposed, a "global interdependence" with no tendency towards equilibrium but containing "pockets of ordering" and "'global fractals', the irregular but strangely similar shapes that are found in very different scales across the world, from the household say to the UN". Urry appears to be arguing both that the world has changed and that complexity theory provides a new ways of looking at the world.

Taking all these writers together, it appears that despite the differences in time and language, there is agreement that individuals interact to produce society which in turn influences them. According to Gilbert & Troitzsch (2005, p.11) emergence occurs when

> "interactions among objects at one level give rise to different types of objects at another level. More precisely, a phenomenon is emergent if it requires new categories to describe it which are not required to describe the behaviour of the underlying components".

Thus societies as a whole are "best considered as emergent phenomena arising from the interaction of social institutions" where 'an institution' is:

> "an established order comprising rule-bound and standardized behaviour patterns. Examples include the family, tribes and other collectivities, organizations, legal systems and so on" (Gilbert, 1995, pp.149, 151-152).

Using this definition, a church, in the sense of an organisation, is an emergent phenomenon (Sawyer, 2005, p.13). Or taking an example from economics, corporations are emergent phenomena in that they are regarded as legal entities in their own right, independent of their directors, shareholders and employees and with characteristics that do not apply to those people, such as profit. A social example is a conversation: it could be said to be emergent as it arises out of the interaction of at least two people and has properties that are separate from those taking part, such as duration, measured by elapsed time.

Furthermore, people can observe and react to emergent properties. This reaction to emergent properties in social systems has been labelled "second-order emergence", "intrinsic emergence" or "immergence" (Gilbert & Troitzsch, 2005, p.10; Cederman, 2005; Sawyer, 2005, p.172). This is an important feature of social systems. For example, norms are generated and maintained. Another example, from economics, is given by the emergence of prices from the operation of markets. In terms of the subject matter of this study, a traffic jam is an emergent feature (Sawyer, 2005, p.3). To sum up, society should be seen as a dynamic, emergent social phenomenon – i.e. with characteristics independent of individuals – yet created by the interaction of individuals.

1.2 Modelling

This Section defines modelling and explains its benefits.

Definition

By a model I mean a set of explicit, quantifiable statements that describes a process: where

- ‘explicit’ means that it can be examined and tested by others (Epstein, 2008) and
- ‘quantifiable’ means it uses numbers rather than verbal descriptions.

Thus Weber’s ‘ideal type’ is not a model as defined here. However, a model can take many forms although it is always a simplification (Gilbert & Troitzsch, 2005, p.19).

Model building is an iterative process that may start with either observation or theory. A phenomenon may be observed through data, which could come from sources ranging from ethnographic studies to national surveys and administrative data. Alternatively, the process may start with an hypothesis: i.e. a possible, testable explanation that draws on concepts developed in the discipline. The hypothesis must then be translated from a verbal description to a mathematical or computer model. Macy & Willer (2002) suggest that “computer simulation is more tractable (but less generalizable) than mathematical modeling and more rigorous (but less nuanced) than natural language”. As van der Leeuw (2005) put it:

> “models enable researchers to economically describe a wide range of relationships with a degree of precision usually not attained by the only other tools we have to describe them: natural languages”.

The model should be “fruitful” in that it contributes to the further development of the theory, and may suggest new data collection and more modelling (Friedman, 1953, p.10). For instance, Keynes’ and Hicks’ macroeconomic theories resulted in the definitions of national income and consumption that are now used to collect data and build macroeconomic models (Akerlof & Shiller, 2009, pp.15-16). Thus modelling is part of an iterative process:

> “True advance can be achieved only through an iterative process in which improved theoretical formulation raises new empirical questions and the answers to these questions, in their turn, lead to new theoretical insights.” (Leontief, 1971).

Benefits of modelling

Modelling is not an alternative to the traditional sociological methods of observation, interview and survey. Indeed, without this data collection modelling would be impossible and better data collection procedures are needed (Boero & Squazzoni, 2005; Moss & Edmonds, 2005). Modelling is rather a way of consolidating the data that is available, bringing together the qualitative and the quantitative. To quote Barth (cited by Cederman, 2005):

> "Explanation is not achieved by a description of the patterns of regularity, no matter how meticulous and adequate, nor by replacing this description by other abstractions congruent with it, but by exhibiting what makes the pattern, i.e., certain processes. To study social forms, it is certainly necessary but hardly sufficient to be able to describe them. To give an explanation of social forms, it is sufficient to describe the processes that generate the form".

A major limitation of the 'traditional' qualitative and quantitative sociological studies is that they are essentially static: they show a snapshot at one point in time. Longitudinal studies lasting over several years are rare. Some long-running studies (such as the Government's *Family Spending Survey* and *General Household Survey*) repeat a few questions at regular intervals over many years but these surveys date only from the 1960s or later.

Furthermore, these surveys only asked questions that were of interest at that time. This highlights a fundamental problem in studying new technology. By the time the technology has been widely adopted and the need for study is recognised, it is too late to examine the 'before' state. For example, it is difficult to obtain information from people today about life before mobile phones even though they have been widely available only since the late 1990s; and only those who are middle-aged and older are able to recollect life before fixed-line phones were ubiquitous. It is therefore very difficult to obtain information about the process of change, the dynamics. Modelling can be used to test theories about these dynamic processes.

In other words, modelling facilitates experimentation. The difficulty of experimentation has proved a major stumbling block in the development of social science as experimentation on people is almost impossible for practical and ethical reasons: outside medical research, there are very few circumstances where it is acceptable to apply some 'treatment' to one group of people and not to another and observe the differences (Gilbert, 2007, pp.10-11).

The act of model building itself helps researchers to think about a problem and is particularly helpful in multi-disciplinary work (van der Leeuw, 2005). The process of modelling can help to clarify an idea (Agar, M., 2003, para 5.2), to expose implicit assumptions that might not otherwise have been appreciated, to identify variables that had not been considered, to raise questions of definition or about the form and dynamics of relationships and to help assess the relative importance of various factors suggested by observation and theory.

Of course precise quantification is rarely if ever possible in social sciences, but it is possible to produce indicators of orders of magnitude, likely ranges and 'best estimates'. These can indicate whether the theory might explain the observed data. But explanation is not the same as prediction. As Epstein (2008) pointed out, we can explain earthquakes in terms of plate tectonics but we cannot predict exactly where and when the next earthquake will occur. Economic forecasts, for instance, have proved to be notoriously inaccurate. It is sometimes argued (for example, Byrne, 1997) that it is impossible to make forecasts if the system is 'complex', society is a complex system, so forecasts of social trends are impossible. However, this argument appears to confuse 'complex' with 'chaotic'. Chaotic systems are a special type of complex system that are very sensitive to initial conditions and perturbations, and in chaotic cases long-term prediction is indeed impossible (Strogatz, 1994, p.3). But society is not generally regarded as a chaotic system. Thus having built a model of a complex system it is always possible to run it forward to see what would happen. The non-linear nature of the system may mean that major changes are unpredictable and it may be preferable to avoid calling the results forecasts, but it certainly can answer the questions such as "What if present trends continue?" or "What if policy A is followed rather than policy B?". Indeed, models can illuminate important trade-offs and indicate where boundaries might lie.

Based on Epstein's (2008) response to the question "Why model?", I suggest that there are four key reasons to model:

- to test theories of explanation;
- to explore dynamics;
- to formulate questions (and thereby guide data collection);
- to examine possible outcomes.

Some 60 years ago Merton (1949, quoted in Boero & Squazzoni, 2005) provided a nice summary:

> "the challenge of social science within range is neither to produce big, broad and general theories of everything, nor to spend time in empirical accounts per se, but to formalise, test, use and extend models to shed light on the causal mechanisms that are behind the complexity of social phenomena".

1.3 Types of Models

There are, of course, different kinds of modelling available and so having decided that modelling is the appropriate methodology, the next stage is to consider the type of modelling approach to use. Two basic classes of models are relevant here: statistical models and simulation models (Gilbert & Troitzsch, 2005, p.16). Statistical models focus on correlations between variables, typically at one point in time (Gilbert & Troitzsch, 2005 p.18). In contrast, simulation models can be used to investigate dynamic social processes (Gilbert & Troitzsch, 2005, p.18; Monge & Contractor, 2003, p.100). The development of computational social simulation modelling started in the early 1960s (Gilbert & Troitzsch, 2005, p.6) with systems dynamics. Next came microsimulation, followed by agent-based simulation. The rest of this Section describes each simulation method in turn.

Systems dynamics

Systems dynamics modelling is a macro, top-down approach. It uses equations to model how a system of interacting variables moves from one state to another over time. For example this approach was chosen by UK phone supplier BT to model phone uptake (Lyons et al, 1997). While such models can be very simple – as illustrated in Box 1.3.1 – they add little to our understanding of the underlying dynamic processes.

Box 1.3.1: Example of a systems dynamics model of technology adoption.

The logistic equation, devised by Verhulst in 1838 to describe the growth of populations (Strogatz, 1994, pp.22-23) can be used to produce a simple adoption model that displays the classic S-curve.

Working through the mathematics and translating the equation into words, it says that the take-up at any given time depends on the take-up in the previous period and the growth rate. Specifically the increase between one year and the next is given by:

% adopters x % of non-adopters x % growth rate

Thus if adoption is currently 20 percent and the growth rate is 10 percent, then adoption next year will be (20% x 80% x 10% =) 1.6 percentage points higher i.e. 21.6 percent.

Because of the way in which the change in adoption depends on the level of adoption, the system is said to be non-linear (Strogatz, 1994, pp.9-10).

Microsimulation

Microsimulation takes a set of data about a population – of people, households or firms – and applies rules to reflect changes, enabling the modeller to look at the overall impact (Gilbert & Troitzsch, 2005, p.8). Unlike the systems dynamics approach, which focuses on changes to distributions at the population level, microsimulation models permit changes to each element of the population distribution (Macy & Willer, 2002). Such an approach is particularly useful for modelling policy changes, to see who is made better or worse off by tax changes for example. However, although allowing for differences between individuals, microsimulation does not represent the interaction between them (Macy & Willer, 2002). For that, agent-based simulation is required.

Agent-based models

> "The best way to determine which social properties are real, to determine the proper relation between individual action and social structure, to determine the role of symbolic interaction in the micro-macro link, and to identify the full complexity of the mechanisms of social emergence is to combine the empirical study of socially embedded communication with richly constructed artificial society models" i.e. agent-based models (Sawyer, 2005, p145).

Agent-based simulation grew out of research on nonlinear dynamics and artificial intelligence and was facilitated by the arrival of personal computers in the 1980s and early 1990s (Macy & Willer, 2002; Gilbert & Troitzsch, 2005, p.6). An agent-based model is a computer program that creates a world of heterogeneous agents in which each agent interacts with other agents and with the environment. These simple, local interactions can generate complex, emergent behaviour, global patterns that can be compared with macro phenomena such as diffusion of information or technology (Gilbert & Troitzsch, 2005, pp.11-12; Macy & Willer, 2002). (See Section 1.) Yet it is more than that, for it establishes a link between the individual and the group, between the local and the global, between the micro and the macro. The key feature that differentiates agent-based models is that interaction between heterogeneous agents is allowed, unlike microsimulation which permits heterogeneity but not interaction and systems dynamics which permits neither. (For an exploration of the difference between agent-based and systems dynamics models, see Hamill, 2007).

Macy & Willer (2002) summarised the situation thus:

> "Computational sociology has traditionally used simulation to forecast social trajectories based on statistical associations, using models that are highly realistic, empirically grounded, and holistic. In contrast, agent-based models use simulation to search for causal mechanisms that may underlie statistical associations, using models that are highly abstract and microsocial."

Van Dyke Parunak et al (1998) argued that agent-based modelling "is most appropriate for domains characterized by a high degree of localization and distribution and dominated by discrete decisions". Agent-based models are particularly well-suited to use for experimentation (Macy & Willer, 2002; Cederman, 2005; Moss & Edmonds, 2005). In agent-based models, both the structure of the world and the types of interaction can be varied and the different outcomes compared.

Macy & Willer (2002) claimed that "sociology has lagged behind other social sciences in appreciating this new methodology" and the Foresight report (2006a, p.26) described it as an "exciting area of development". In their introduction to the special issue of the *American Journal of Sociology* devoted to agent-based modelling, Gilbert & Abbott (2005) argued that:

> "the most important changes in social science computation have come in the use of computers to 'think through' the implications of human actions within given social structures–action in networks. Such 'agent-based modeling' has been applied to everything from the diffusion of norms and innovations to voting."

1.4 Agent-based Modelling of Transport and Communications

Agent-based modelling been little used in transport. Transport modelling has, however, been undertaken since the mid-1950s using the "four stage model" to answer the questions how many trips will be made, to where, by what mode and which route? (Batty, 1997; Bates, 2000.) Hensher & Button's 600-page *Handbook of Transport Modelling* published in 2000 has no reference to agent-based modelling. But since 2000 there have been five workshops in *Agents in Traffic and Transportation* with papers published in Transportation Research C (Klügl, 2009) although interest in that forum has focused on freight and logistics: for example Davidson et al (2005). Transport-related agent-based models are designed to answer the same questions as the earlier four-stage models and tend to be geographically based: they model traffic within a city, a region or even whole country. For example, the US model, TRANSIMS (2008) is a very detailed, activity-based

> "agent-based simulation system capable of simulating the second-by-second movements of every person and every vehicle through the transportation network of a large metropolitan area."

Raney et al (2002) took a similar approach to model traffic across the whole of Switzerland. At the other extreme, Klügl & Bazzan (2004) looked at drivers' decision-making while commuting and both UCL's Centre for Advanced Spatial Analysis (2008) and Lotzmann & Mohring (2008) have examined flows of pedestrians.

Although there are ad hoc studies, such as that by Lyons et al (1997) referred to above, there is no comparable body of literature dealing with communications. This may be, in part, due to the fact that provision of electronic communications has, in the UK, been largely left to the private sector in recent years while provision of highway infrastructure has remained the responsibility of the public sector.

However, Mokhtarian & Salomon (2002) identified three modelling approaches to identifying the relationship between communications and travel:

- macro modelling of the relationship between transport and communication sectors in the economy such as Selvanathan & Selvanathan (1994) – discussed in Chapter 2 – but they concluded that such methods "offered no insight into behavioural or other causal mechanisms".
- application-specific micro studies that "take a given set of telecommunications-based activities and attempt to calculate the net impact on travel", usually based on survey data.
- activity-based micro studies based on time-use diaries. This is a recently developed method.

No mention is made of agent-based modelling.

This newness means that the techniques are still under development. The use of agent-based modelling is therefore part of the novelty of this thesis. Indeed, this project goes into areas that are still regarded as "difficult" (Gilbert, 2006): innovation, culture, networks and history.

1.5 Agent-based Models in this Thesis

This Section describes and justifies the type of agent-based models used. Agent-based models can be divided into three broad types (David et al., 2004; Boero & Squazzoni, 2005):

- highly abstract models;
- theoretically based models for investigating phenomena that share common features;
- case-based models.

This thesis uses the latter two types. In other words, they fall between detailed evidence-based models and more general, abstract models. They are neither examples of Axelrod's KISS ("Keep It Simple, Stupid") models nor of Edmonds & Moss' KIDS ("Keep It Descriptive, Stupid") models (Hassan et al, 2008). There is arguably nothing wrong with that: "Neither the KISS nor the KIDS approach will always be the best one, and complex mixtures of the two will be frequently appropriate" (Edmonds & Moss, 2005). A case for doing just that has recently been made by Janssen (2009, para 5.5). A model of social networks (presented in Chapter 3) is used to create the basis of a general theoretically-based model of the adoption and use of communication modes (presented in Chapter 5) to develop case studies (in Chapters 6, 7 and 8) that together cover the years from 1840 to 2021. The justification for taking this long view is set out below.

Although some have argued that theories of social change should be "grounded" in historical analyses (Stinchcombe, 1978, p.1; Tilly, 1981, pp.7-8) others have claimed that that history and sociology are different disciplines, addressing different questions. Weber (1921/1968, p.19) distinguished between sociology and history thus:

> "Sociology seeks to formulate type concepts and general uniformities of empirical processes. This distinguishes it from history, which is orientated to the causal analysis and explanation of individual actions, structures, and personalities possessing cultural significance".

Following this line, Burke (1980, p.33) claimed that history is the study of particular events while sociology is concerned "with general laws". However, Goldthorpe (1991) claimed that sociology must “always be a historical discipline”. Tilly (1981, p37) argued that “sociology grew out of history” and dismissed this “conventional division between ‘generalizing’ and ‘particularizing’” (ibid, p.7). Instead he said that historical analysis is distinguished from sociology by its “integration of time and place”, adding that sociologists attempted to create a “timeless natural science of society” (ibid, p.38). Giddens (1979) argued that by re-introducing time into sociology, the two disciplines became “methodologically indistinguishable”. While not supporting Giddens’ strong view, Abrams (1980) acknowledged that there is “common ground” in that “both seek to understand the puzzle of human agency and both seek to do so in terms of processes of social structuring”. Thus for example events in the life of Queen Victoria are the concern of history and not sociology while both disciplines have a legitimate interest in the everyday life of people during her reign.

Nevertheless Goldthorpe (1991) argues that sociologists interested in social change should only turn to history when other means, such as “life-course, cohort or panel studies” are not available, that is when:

> “their concern is with social change that is in fact historically defined: that is, with change not over some analytically specified length of time - such as, say, ‘the life-cycle’ or ‘two generations’ - but with change over a period of past time that has dates (even if not very precise ones) and that is related to a particular place.”

This is because, he argued, historians are always restricted by the availability of material that has survived from the past while sociologists can collect new data. Yet Tilly (1981, pp.13-14) claimed “the supply of information about the past is almost inexhaustible” and the problem faced by historians is to select which data to use. But Goldthorpe has a more subtle point concerning data. When sociologists use historical data, he complained, they usually use the analysis of others, thus “grand historical sociologists” are offering “interpretations of interpretations”.

As noted in Section 2, there is a particular problem in studying the impact of new technology in that it is simply not possible to look at the ‘before’ situation in the present. Thus I believe that this case meets Goldthorpe’s criterion for using history in sociology. This thesis is looking at changes over many lifetimes, not just one or even two. As for the problems with using historical data these are, in my view, no different in kind from using modern secondary sources, although in practice they have to be treated with even greater care. I take the line espoused by Phelps Brown (1972) in his presidential address to the Royal Economic Society, that by studying history, “we do gain understanding: our experience and awareness are extended, our practical judgment is informed”.

Nevertheless, it is argued that the current digital communications revolution is somehow different from what has been seen before and the past is not relevant. For example Cairncross (2001, p.3) said:

> “The innovations taking place in electronic communications will be far more pervasive than some of the advances with which they are often compared such as the railways or the telegraph”.

However, Cairncross underestimated the impact of the railways. For example:

- according to Cairncross (2001, p.1) the car liberated women to travel yet Simmons (1991, pp.332-3) pointed out, as early as 1844 it was noted that the railways had enabled “the fair sex, and particularly of the middle and higher classes” to travel independently.
- according to Cairncross (2001, p.2) planes facilitated the growth in tourism enabling “ordinary tourists to visit places that were once the preserve of the rich”. Yet in 1832, it was predicted that Brighton would be ruined for ‘fashionable society’ by the arrival of the railway (Simmons, 1991, plate 41): different times and places, same phenomenon.

Aldcroft (1992, p.75) talked about the “enormous influence the railways had on society as a whole. In terms of mobility and choice, they added a new dimension to everyday life”. I think that much the same could be said for the current digital communications revolution.

Ling et al (2005, p.81) noted “communications sent via new mediation systems must necessarily draw on elements from existing established genre”. I suggest that the ‘death of distance’ has been a continuing process, punctuated by significant changes in technology. Unlike Cairncross (2001), I do not believe that what we are seeing today is essentially a new phenomenon but rather a continuation of a very long historical trend and thus there are lessons to be learnt from the past about what is happening today and what might happen tomorrow.

Agent-based models can make a significant contribution to the understanding of the past. Two notable examples are:

- The Evolution of Organised Society (EOS) project looked at the development of the Upper Palaeolithic society in France that is associated with the well-known cave art. An agent-based model was used to examine how the society could have evolved from hunter-gatherers to become more complex, centralised and territorial due to environmental changes that affected the food supply. In the model, agents were able to "perceive their environment and other agents, formulate beliefs about their world, plan, decide their courses of action and observe the consequences of their actions". The model showed that, by grouping together, agents had a better chance of survival when resources were scarce and that, if hierarchies formed, they continued even if there were temporary disruptions. (Gilbert & Triotzsch, 2005, pp.195-197; Doran & Palmer, 1995; Gilbert, 1995).
- The Anasazi tribe in the south-west of the United States were a near-subsistence level farming community who survived for some 3,000 years before disappearing about 1300, leaving a substantial archaeological record. The aim of the project was to gain some understanding as to why they disappeared: was it a result of environmental or cultural changes? Although the model included "only the most basic environmental and demographic specification", it was able to reproduce the change in population size and distribution and provided "a clue" to the relative importance of these factors. By quantifying the fertility and mortality of the population, their food requirements, the size of their harvests and so on, the model made it possible to assess the "relative magnitude" of the environmental and social determinants. The model suggested while environmental factors were important, the tribe could have survived and thus other factors, perhaps cultural or disease, played a role (Axtell et al, 2002; Axtell, 2006). (This model was recently confirmed by Janssen, 2009.)

Both these projects were substantial, involving many person-years of effort (Gilbert & Triotzsch, 2005, p.197; Axtell, 2006). Here the aim must, of necessity, be more limited.

Sawyer (2005, p.162) noted that current models either generate the micro-to-macro processes while the macro-to-micro are programmed, or vice versa, and argued that attempts should be made to do both simultaneously. Full dynamical models of society, as envisaged for example by Asimov (1951/1975) in *Foundation* may be a laudable long-term aim but at this stage neither the data nor the modelling techniques are sufficient to produce such models. As Moss & Edmonds (2005) said: “much descriptive modelling at a low concrete level will probably be necessary before successful and useful more general theory can be developed”. I suggest that there is a case for obtaining a better understanding of social processes by using simple models in narrow domains. In particular I propose that the micro-to-macro processes will be generated, leaving macro-to-micro links – ‘practices’ or norms – to be imposed.

1.6 Building, Running and Testing Agent-based Models

This Section explains in general how agent-based models are built, and how they can be tested. (Further technical issues will be discussed as they arise.)

Building an agent-based model

The model comprises agents in a space. The agents themselves are models of actors in the sociological sense. Usually, an agent represents a person, but it can represent a household, a firm or even a nation for example (Gilbert, 2007, p.15). Heterogeneity of agents is a key feature of this modelling system: each agent may have a unique set of characteristics and behaviour rules (Epstein, 2006, p.51). The agents are distributed across a space envisaged by the modeller which may represent a landscape or a social network for example (Epstein, 2006, p.52). They may be distributed randomly across the whole space or according to some other principle. The space is typically two dimensional and may have boundaries or be continuous. The behaviour rules specify how agents interact with neighbours or their local landscape.

Various packages are available with which to build such models. NetLogo (Wilensky, 1999) was chosen because it is the most accessible to those who are not expert programmers, while providing sufficient flexibility to build all but the largest and most complex models (Gilbert, 2007, pp.80-1). "NetLogo is a programmable modeling environment for simulating natural and social phenomena", largely written in Java. (Wilensky, 1999). It is "particularly well suited for modeling complex systems developing over time. Modelers can give instructions to hundreds or thousands of 'agents' all operating independently. This makes it possible to explore the connection between the micro-level behavior of individuals and the macro-level patterns that emerge from the interaction of many individuals" (ibid). It is well-documented, with a manual and a model library, and is supported by an online community. However, it can run slowly. Also, it is also not well set-up for collecting and analysing output. This was done by producing .csv files which were then assembled into Excel files using macros. All the models reported in this thesis were produced using version 4.0.4.

According to Wooldridge and Jennings (1995, cited in Gilbert & Troitzsch, 2005, p.173) agents typically have autonomy, social ability, reactivity and proactivity. Gilbert (2007, p.37) and Macy & Willer (2002) explained these terms as follows:

- autonomy: there are no authorities telling agents what to do, rather the agents follow the rules that are programmed; they are self-organised
- social ability: agents interact with one another, for example, influencing and imitating
- reactivity: agents react to their environment, sometimes indirectly influencing one another by changing their shared environment
- proactivity: agents can take the initiative to pursue their own goals.

These ideas are, however, rather difficult to implement. Gilbert (2007, p.37) suggested an alternative formulation of agents' characteristics:

- perception: agents "can perceive their environment", including other agents in the vicinity
- performance: agents have "a set of behaviours that they are capable of performing" such as moving and communicating
- memory: of their "previous states and actions"
- policy: "rules, heuristics or strategies" that determine what they do next.

Agent-based modelling comprises four steps (Gilbert, 2007, pp.52-55; Windrum et al, 2007, paras.4.4-4.6):

1. Identify a set of 'stylised facts' to be reproduced or explained: a stylised fact is "a simplified presentation of an empirical finding" (Gilbert, 2007, p.127), usually at macro level.
2. Build a model which reflects evidence about micro behaviour. This involves specifying the agents and their behaviour in different circumstances, how they interact with one another and with their environment.
3. Use the stylised facts to limit the parameters and initial conditions.
4. Use the model to explore the determination of the stylised facts including verification – checking whether the program is working as expected – and

validation – assessing whether the simulation is a good model of the process under examination.

Verification and validation

As noted in Section 2, building a computer model requires translation of a theory, or set of theories, into a computer program. Two distinct types of verification are therefore necessary.

- The first is a mechanical process, to check that the program is doing what is intended. This is an ongoing process, in particular, involving step by step programming and other articles of "good practice" as set out, for example, by Gilbert (2007, pp.64-67). For example, if *x* should be divided by *y* then it can be checked that *x* is indeed being divided by *y* by looking at the intermediate output.
- The second is to check that the model appropriately reflects the concepts and the theory, a more difficult process.

The models presented in this thesis were verified as appropriate.

Validation is yet more contentious. Because agent-based models are stochastic, the output of each runs varies (Gilbert, 2007, p.55). This raises two questions.

- How many runs should be produced?
- How should these runs be compared with the observed data?

The more runs, the more confidence can be placed in the results. But the more runs, the longer the time taken and the larger the data files to be analysed. There is no clear guidance on this topic. Basic statistical theory suggests 30 is sufficient and frequently 30 or 50 runs are undertaken (e.g. Axtell et al, 2002; Epstein, 2006). The results reported in this thesis are based on 30 runs, with one exception (noted in Chapter 4). To compare the output of the model with observed data, the average for each period over a set of runs is taken although this average may never actually be seen in any particular run (Axtell et al, 2002). To provide an indication of the variability, the standard deviation is frequently quoted.

Goodness of fit can be measured using standard statistical measures. If the model does not remotely fit the data then it cannot be a good model. Friedman (1953, pp.8-9) argued that "the only relevant test of the validity of a hypothesis is comparison of its predictions with experience" although, in line with Popper (1935/1972, p.41), he added "factual evidence can never 'prove' a hypothesis, it can only fail to disprove it". For instance, because communication and travel have both risen over time, it is easy to create models that show both rising over time. If X rises over time and so does Y, is X causing Y? Or Y causing X? Or are both caused by a third factor, Z, which may simply be time? As Friedman (1953, p.9) elegantly put it: "Observed facts are necessarily finite in number; possible hypotheses, infinite". In other words, many models can fit the data. This is variously described as "underdetermination" or the "identification problem" (Moss, 2008) and, it is argued that it is a more serious problem in non-linear systems than in linear systems (Richardson, 2002). More recently, and in the context of agent-based models, Epstein (2006, p.53) stated "generative sufficiency is a necessary but not sufficient condition for explanation". To be judged a good model, it must also make sense at the micro level (Epstein, 2006, p.53).

While goodness-of-fit can always be improved by adding more explanatory factors, there is a trade-off between goodness-of-fit and simplicity. Too much fine-tuning can result in reduction of explanatory power because the model becomes difficult to interpret. At the extreme, a model "might become as complex as the real world and therefore just as difficult to analyze as the phenomenon being simulated, providing no explanatory power" (Sawyer, 2003). There is, therefore, a paradox here to which there is no obvious solution. Despite its apparently scientific nature, modelling is a matter of judgement. Doran & Palmer (1995) advocated

> "A standard modelling principle is that the level and complexity of a model should be chosen so that it answers the questions and embodies the theoretical elements we are interested in, but is otherwise as simple as possible."

That principle is followed here.

Sensitivity analysis and the investigation of counter examples should be undertaken. Sensitivity analysis takes key variables and changes them by small amounts. This is particularly useful if there is uncertainty about the exact value: for example, the sensitivity of the results to adding or subtracting 10 percent to the variable in question can be tested. Using counter-examples takes key variables and assumes that they behaved quite differently. For example, if it were known that there was economic growth over the period being modelled and this has been built in to the model, then a counter example is to run the model with economic growth set to zero. In this way, the characteristics of the dynamic process modelled can be explored.

To sum up, the aim of validation is to see to what extent the observed macro level patterns can be explained by micro level interactions. For example, by assuming certain values that seem reasonable from the literature, be they characteristics of agents or types of interactions, can the aggregate statistics be explained? Goodness of fit is necessary, but not sufficient. To be acceptable, the model must pass the macro goodness-of-fit test and be based on justifiable micro assumptions.

1.7 Summary and Conclusion

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), other views based on the agency-structure duality and more recent ideas about society 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.

The next Section discussed modelling. A model was defined as a set of explicit, quantifiable statements that describe a process. It was argued that building such models is important in promoting the scientific analysis of social phenomena and these models 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.

Section 3 explained that agent-based modelling is chosen for this thesis because it offers a way of looking at 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, as noted in Section 4, has not been used extensively in the modelling of transport and communications. Different types of agent-based models were discussed in Section 5, which also touched on the relationship between sociology and history and the useful contribution agent-based models could make to our understanding of the past. The principles that underlie the building and testing of agent-based models were set out in Section 6 and it 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

Time and money are both scarce resources. Juster and Stafford (1991) argued that time is "the fundamental scarce resource". There are only 24 hours in a day and we have to decide how to allocate our time between competing demands within this fixed time budget. If we want to do something new, we have to give up something else. The longer time people spend working, the more money they have to spend but the less time in which to spend it: "the consumer's problem is therefore to allocate time and money income" (Gravelle & Rees, 2004, p.82). While there can never be more than 24 hours in a day, incomes can rise (or fall). Hägerstrand (1970) also identified 'capability constraints' of time and distance. The key time constraints are the biological needs to sleep and eat. The distance constraint depends on the "ability to move or communicate *and* the conditions under which he is tied to a rest-place". New modes of communication and transport have relaxed this distance constraint.

This Chapter looks at the relationship between time and money, communication and travel. Three questions are addressed:

- 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?

Consumption has been studied in all three social science disciplines, most notably economics (Baudrillard, 1970/1998, p.69; Fine, 2002, p.155). Although economics can be criticised for its narrow view and its restrictive assumptions (see, for example, Fine, 2002 pp.125-154), it is the study of the allocation of scarce resources and so this Chapter primarily uses tools developed by economists. The first two Sections discuss the budgeting of time and money respectively. Section 3 examines the relationship between expenditure on communications and expenditure on transport. Section 4 returns to the three questions.

2.1 Budgeting Time

Measuring time use is not straightforward for two main reasons. First, the way the time use data is collected can affect the results (Juster & Stafford, 1991; Gershuny, 2003). Second, there is the problem of how to record activities. Howsoever detailed are the categories used, there remains the problem of multitasking. If you are watching TV while doing the ironing, how is that recorded? More particularly, if you are using your computer to order your groceries, are you shopping or computing? Yet the overall picture from a wide range of sources is remarkably consistent. This Section starts by describing the pattern of time use in 2005. It then looks at how time use has changed in two key areas: working hours and the use of leisure. It then turns to time spent communicating and finally, time spent travelling.

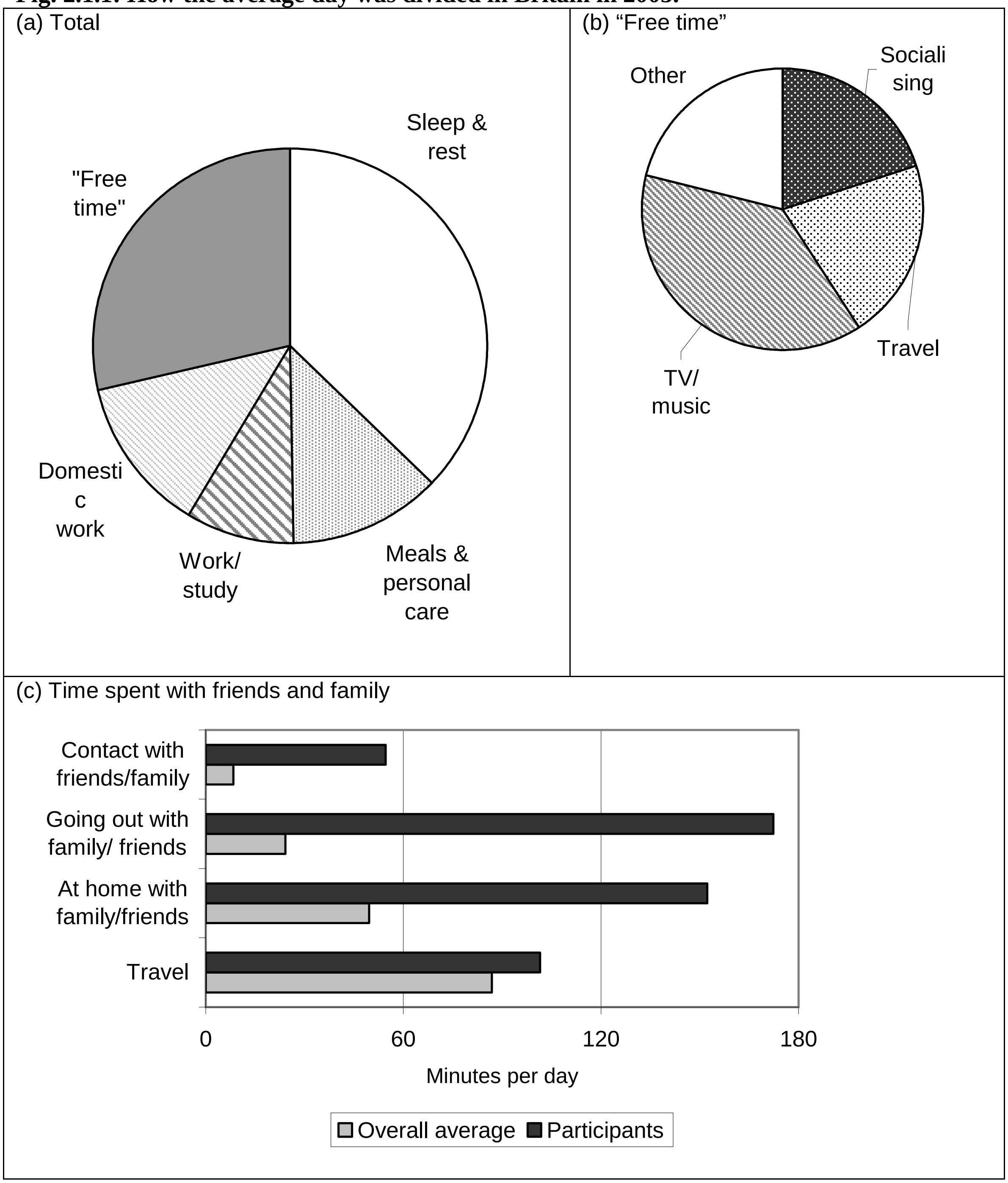
Time use in 2005

Following Gronau's (1977) broad classification, Fig 2.1.1 shows how people in Britain in 2005 on average spent their day, the average being taken over all adults, working and non-working:

- nearly half of their time was taken up with personal and biological maintenance such as eating and sleeping;
- a quarter was spent on paid work and unpaid domestic work, which a third party could be paid to do;
- over a quarter was left free for other activities, generally leisure where third-party production is conceptually impossible: 40 percent of free time was spent socialising and travelling (including commuting) (top right panel).

However, these averages disguise the fact that most people reported travelling, but only a minority reported having contact or going out with friends and family or spending time at home with them. Thus those who did report socialising spent much longer than the averages indicate: between 1 and 3 hours (bottom panel).

Fig. 2.1.1: How the average day was divided in Britain in 2005.

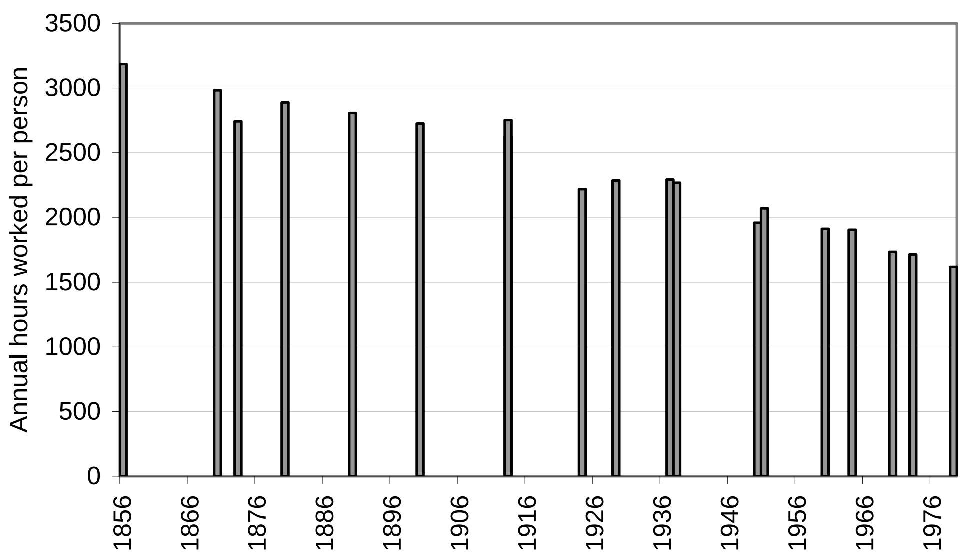


Source: ONS (2006a, pp.22-23).

Changes in time use: less work, more leisure

Over the long term, the main change in time use has been a reduction in work hours. Gershuny (2000, p.32) noted that "industrialising societies" are associated with "long hours of work for the subordinate classes" whereas "modern/post industrial societies" are associated with "declining work time providing opportunities for increasing consumption". Fig. 2.1.2 shows that from the mid-nineteenth century to 1979 the average hours worked halved, mostly due to the reduction in full-time working hours, particularly for manual workers between the 1950s and 1970s (Matthews et al, 1982, pp.66-67; Gallie, 2000 pp306-7). "For the wider workforce, the picture from 1979 to 1998 is one of remarkable stability" (Gallie, 2000, pp.306-7). Since 1998, this trend to shorter hours appears to have continued: while about a quarter usually worked more than 45 hours a week in 1998, this had fallen to a fifth by 2007 (ONS, 2007a, Table 8).

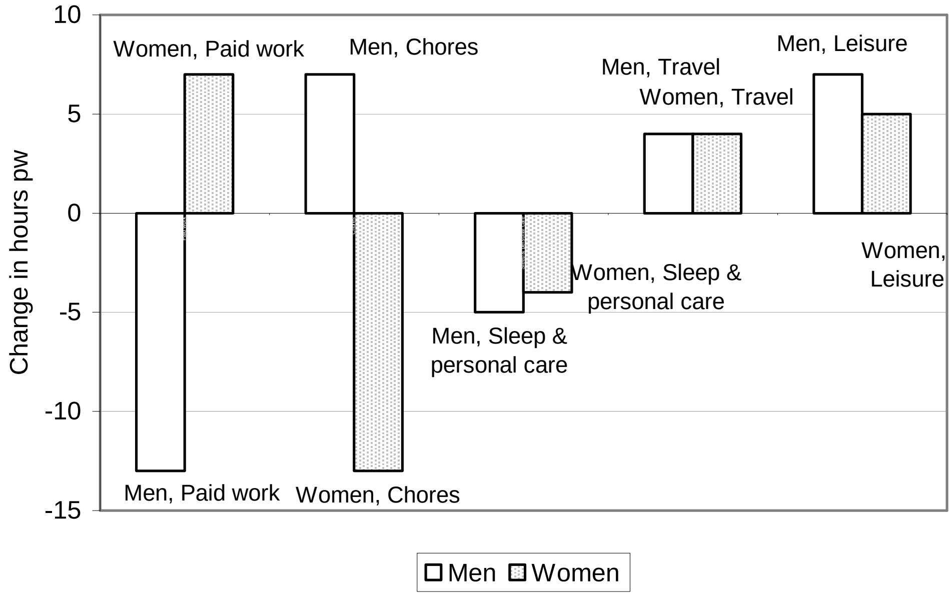
Fig. 2.1.2: Annual hours worked per worker: UK: 1856-1979.



Sources: Matthews et al (1982, p.65); Castells (2000, p.469).

However, these averages disguise a very important shift over the last half century or so, namely the move of women into paid work. Since 1961, for men on average, there has been a reduction in paid work and an increase in unpaid work; for women, the opposite, as shown in Fig. 2.1.3 (Partridge, 2005; Gershuny, 2002). Nevertheless, women still have more leisure now than in 1961.

Fig. 2.1.3: Change in time use between 1961 and 2000: adults, 25-65: UK.



Source: Gershuny (2002, Table 1 – based on data from the BBC, ESRC and BT.)

These figures seem to counter the popular view that we now have less leisure time. Partridge (2005) suggested that moving from single to dual income households has, by reducing the time that neither partner is working, created the perception of lack of leisure time. In addition, Gershuny (2000, pp.5-7) argued that in "the developed world in the last third of the twentieth century", there has been "a reversal of the previous status-leisure gradient. Those of higher status previously had more leisure, and subsequently had less of it than those of lower social status". Partridge (2005) argued that because it is these "high status" individuals who write academic and media articles that there is a perception that there is a shortage of time.

It was envisaged that as economies grew, people would enjoy more leisure. For example, in 1931 Keynes suggested that "with no important wars and no important increases in population" by 2030 there would be a 15 hour working week with the main problem being how to use our leisure (Keynes, 1931, p.369). There has, of course, been a major war (World War 2) and the UK population has increased by about a third (ONS, 2009a). So, although working hours have fallen, they have not fallen as much as Keynes predicted. It appears that people have chosen to take some of the benefits of economic growth in terms of more consumption rather than more leisure. (Technically, the substitution effect – using higher income to buy more goods – has outweighed the income effect – buying more leisure (Gravelle & Rees, 2004, pp.77-85)). Put more prosaically, earning more money and having less, but higher quality, leisure is preferred to having less money but more time. This desire for high quality leisure time emerges from studies of consumption: time-using goods that increase the quality of time spread much faster than time-saving goods that increase the quantity of free time (Bowden & Offer, 1994; Tellis et al, 2003).

Changes in time use: changing leisure

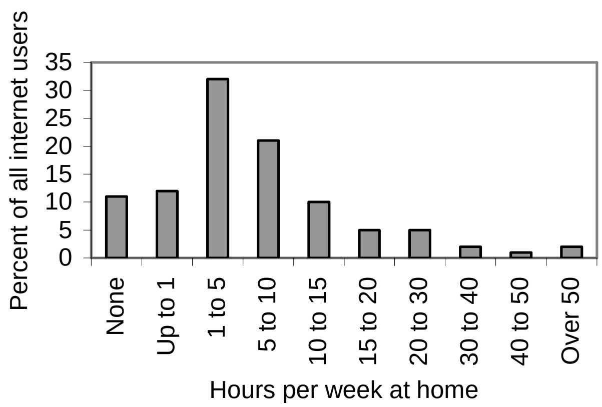
Not only has the amount of leisure time increased, but the use of that time has also changed. As Fig 2.1.1 shows, much time is now spent watching TV. Yet 50 years ago, few people had TV. What activities have been given up to accommodate this increase? The BBC conducted time budget studies in 1939 and 1952 when there were virtually no TVs, and compared the results with a similar study conducted in 1975, when almost every household had one. The BBC concluded that:

> "It could be that the working day has shortened, but there is also the possibility that the attraction of television has reduced the tendency to spend time 'doing nothing in particular'" (BBC, 1978, p.641).

It now appears that the internet is displacing TV; but different research methods produce different results (see for example Kraut et al, 2006). Simple comparisons of users and non-users is misleading to the extent that they are different types of people, the heterogeneity problem: the better educated, who are known to watch less TV also use computers, so the use of computers will be associated with less TV watching but has not necessarily caused it (Gershuny, 2002; Gershuny, 2003). The heterogeneity problem also arises in relation to the impact of broadband on internet use where it was found that broadband users spent longer online than narrowband users (Ofcom, 2007, p.21; Anderson & Raban, 2007, p.47). It is not clear to what extent this finding due to the fact that those who were keener users of the internet were more likely to move to broadband rather than to changes in behaviour (due, for instance, to lower marginal costs when narrowband access is charged per minute and broadband is not).

Yet Anderson & Raban (2007, p.59) argued that “there is simply not that much slack in most people’s lives for major shifts in behaviour in the short term”. This is supported by Gershuny (2007, pp.277-8) who reported that while the proportion of people using a home computer had risen markedly between 1985 and 2005, the time spent using a PC remained at about 2 hours a day. However, by autumn 2007, half of internet users were spending more than 5 hours a week online at home (Fig. 2.1.4) and the average time spent on the internet had increased from 9 minutes a day in 2004 to 25 in 2009 (Ofcom, 2009b, p.18).

Fig. 2.1.4: Time spent online at home: 2007.



Source: Ofcom (2009a, p.279)

Since 2003, time spent watching TV has fallen among young adults “as they divide their time between an expanding range of media consumption activities” (Ofcom, 2009b, p.128). But the picture is blurred by the fact that 40 percent of internet users say that they watch TV at the same time as using the internet (Ofcom, 2008a, Table 109). Time may, however, have been taken from non-leisure activities. While Gershuny (2000, p5) argued that the time spent sleeping can be treated as a constant, Taheri (2006) suggested that children and adolescents found time for TV, computer games and use of the internet and mobile phones at the expense of sleep. By early 2009, a third of internet users thought they spent too much time online (Dutton et al, 2009, p.5).

Time spent communicating

As shown above, people report spending only a few minutes a day communicating. Yet as Emler (1994, p.125) concluded: “people spend a great deal of time in conversational interaction. The average is likely to lie between six and twelve hours a day” and that “should we reflect upon other things that humans might be doing with their waking hours, we can begin to see that very few of the possibilities exclude talk”. Thus the time-study results showing:

> “an average of a mere 15 minutes or so per day devoted to conversation, indicates that the category must wildly underestimate the amount of talking that does occur between persons” (Robinson et al, 1972, p.136)

Yet in the 1965 multinational time use study in which conversation was generally recorded as a secondary activity, some 80 percent of participants in France, West Germany and the US recorded spending only some 2 hours a day in conversation (Robinson et al, 1972, p.140). These findings show that there is a fundamental problem in measuring the time spent on interpersonal oral communication, what could be called the ‘embeddedness’ of talk.

While it may not be possible to reliably measure time spent in face-to-face interaction, in theory it is possible to measure the time spent speaking on the phone. In 2008, on average 4½ hours of voice calls were made a month from residential lines and in addition people were spending over 2 hours a month talking on their mobiles (Ofcom, 2009b, pp.252-3). But even with technologically mediated communication, there remains the problem that people are also doing something else at the same time; this is especially true of mobiles (Partridge, 2005).

Written communication – letters and more recently, text messages and internet-based communication – takes time to compose and read.

- Letters. In the 1840s, some 200 million letters a year were sent: on average less than 10 letters a year per person (Mitchell, 1988, Tables 3 & 14). By 2006, this had risen to 24 billion items or about 400 a year per person (Royal Mail Group, 2006). However, only 10 percent of these 24 billion items of mail were between households: about 40 a year (Postal Services Commission (Postcomm), 2009). These are mostly cards. Postcards were introduced in 1872, and just before the First World War, on average 20 a year were being sent (based on Mitchell, 1988, Tables 3 & 14). It is claimed that in the UK we each give an average of 55 cards – not necessarily sent by post – every year (BBC, 2006). However, this does suggest that much of the person-to-person mail now comprises cards rather than letters. Sending cards takes much less time than writing letters. Indeed, my examination of a set of 22 postcards sent by a family in Wales between 1905 and 1910 found that 7 contained apologies for "not writing", often explicitly claiming lack of time. (Discussed further in Chapter 6.)

- Texts (SMS). By 2008, Ofcom (2009b, p.254) reported that mobile uses averaged 99 texts per month, roughly 3 a day. If each took 5 minutes to compose and send, this would total some 15 minutes a day.
- Internet communication. There is much complaint about the volume of email received (for example, Harper, forthcoming) but there is little firm data. An American survey in 2003 found that just over half of personal inboxes got 10 or less emails a day and only 1 in 10 reported more than 50 messages a day (Fallows, 2003). As with physical mail, only a proportion of emails will be person-to-person: Postcomm (2006, p.28) suggested that on average each email user would receive some 125 direct marketing emails a year, or over 2 a week. People do not report spending very long emailing: 4 minutes a day on average in 1999/2000 (Gershuny, 2002) and in 2005, 7 minutes a day was spent socialising online, doing email and on chatrooms (ONS, 2006a). Instant messaging and the use of social networking is now replacing email for some social contact, especially among younger people (Dutton et al, 2009, p.21). Ofcom (2009b, p.290) reported that in May 2009, the average *Facebook* user spent 6 hours a month on the site.

Two conclusions emerge. First, as measured by time use studies, time spent on technologically-mediated communication is low. Second, people do find time to use new modes of communication. Time, therefore, does not seem to be an important constraint on communication.

Time spent travelling

The average time spent travelling in Britain in 2005 was 87 minutes a day (Fig. 2.1.1 above). Although Fig 2.1.3 shows that time spent travelling increased between 1961 and 2005, this rise occurred before 1975. Since then, whether measured by hours a year or week or by minutes per day, it appears that time spent travelling has remained fairly constant at around an hour a day (Table 2.1.1). Yet, as Mokhtarian & Chen (2004) pointed out, as travel time is seen as a "disutility", something to be avoided, time spent travelling would be expected to fall as travel speeds rise, ceteris paribus.

Table 2.1.1: Change in time spent travelling: 1961 to 2005.

(a) Average hours per person per year spent travelling 1972/3 to 2004. GB.

1972/3	353
1975/6	330
1978/9	376
1985/6	337
1994/5	358
1998/00	359
2004	363

Sources:
To 1994/5: Root (2000, p463)
1998 on: DfT (2006b).

(b) Time use survey data on travel time: 1961 to 2005

	1961	**1973**	**1975**	**1987**	**1999 /2000**	**2005**
Hours per week (1)						
Men	3		7	9	7	
Women	2		5	8	6	
Minutes per day		(2)				(3)
Men		119				92
Women						82
- working		85				
- non-working		57				

Sources:
(1) Gershuny (2002, Table 1)
(2) Sharp (1981, p.155)
(3) ONS (2006a)

Between 1965 and 1999/2001 the average distance travelled per person in Britain almost doubled from 6,000 kilometres to 11,000 kilometres a year; and so did the average distance per trip, from 5 to 11 kilometres (Pooley et al, 2005, p.59). Thus the number of trips hardly changed. Indeed, Pooley et al (2005, p.1) noted that "everyday mobility consists of mainly local travel connected to essential everyday tasks". Mokhtarian & Chen (2004) also noted that despite a constancy at the aggregate level, time spent travelling varies significantly between individuals and at different places and different times implying that increases for some individuals are offset by reductions for others.

(This seems a good candidate for investigation using agent-based modelling, although that line is not pursued here.)

Other evidence suggests that people do adjust their behaviour to keep their travel time roughly constant. On the basis of studies across many countries Graham & Glaister (2002, pp.20-22) reported that increases in travel time by car do reduce the number of trips and in the long run, the distance travelled:

- Changes in travel time have a greater impact in the short run, during which it is possible only to change mode, than the long run, when frequency, destination and location can be changed: a 10 percent increase in time will result in a 6 percent fall in trips in the short run, 3 percent in the long run. Thus they suggest that "having made changes in destinations, travel frequency, and land use locations, car drivers begin to make more trips of lower duration".
- In terms of distance however, the opposite holds: a 10 percent increase in time results in a 2 percent fall in distance in the short run, 7 percent in the long run.

Thus Urry (2004a) concluded:

> "…it seems that people do not spend more time travelling since this appears to have remained more or less constant at around an hour or so per day albeit with substantial variation within any society. Thus there seems to be some limit on the time people will spend extending their networks through travel…"

Jain and Lyons (2008) argued that travel to maintain social networks can be regarded as a gift; and that travel time itself can have a positive utility. However, most travel is not to maintain social networks:

- "visiting friends" accounted for 14.3 percent of trips in 1965 and 17.6 percent in 1999-01 (although the comparison may not be quite exact due to changes in definition) (Pooley et al, 2005, p.59) and
- the average time spent travelling in Britain in 2005 for "exercise or travel for pleasure" was 5 minutes a day (ONS, 2006a, Table 5.17).

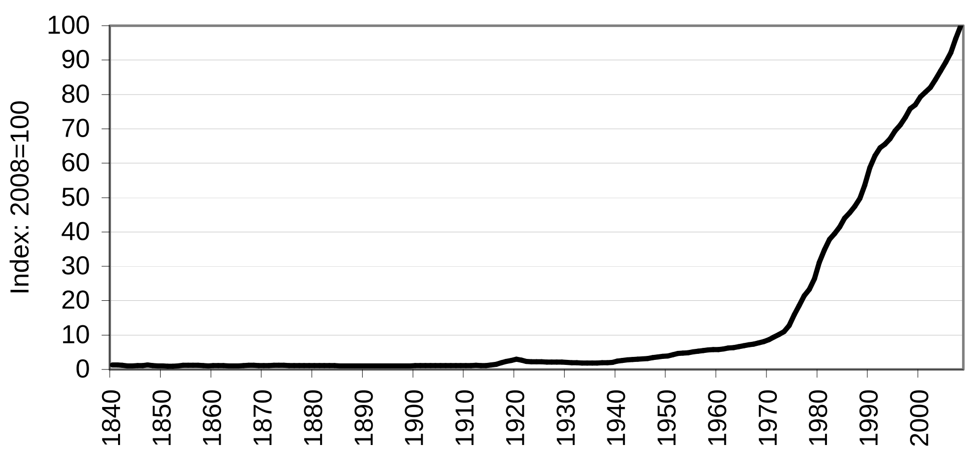
Overall, it does therefore appear that on average travel is constrained by time.

2.2 Budgeting Money

The long term view

Since 1840, both the currency and the value of money have changed. Up until the introduction of decimal currency in 1971, the pound was made up of 20 shillings, designated '*s*'; and each shilling comprised 12 pence, designated '*d*'. Thus there were 240*d* to the pound. In other words 1p today is 2.4*d*. However, £1 today buys much less than in 1840. Measuring price changes over a long period of time poses problems because of the limited availability and quality of data in the more distant past and because what people buy changes (O'Donohgue et al, 2004). Nevertheless, National Statistics produce a series running from 1800 to the present day and part of that series is shown in Fig. 2.2.1. There are two key points to note. First, overall prices changed little from 1840 to the start of the First World War (although they did fluctuate as illustrated below in Fig. 2.2.8). Second, since the second half of the nineteenth century prices have risen about eighty- or ninety-fold, depending on which year is taken. So, very roughly, a pound in 2008 buys the same as 1p or about 2½*d* would have bought in the second half of the nineteenth century.

Fig. 2.2.1: Index of prices: 1840-2008.

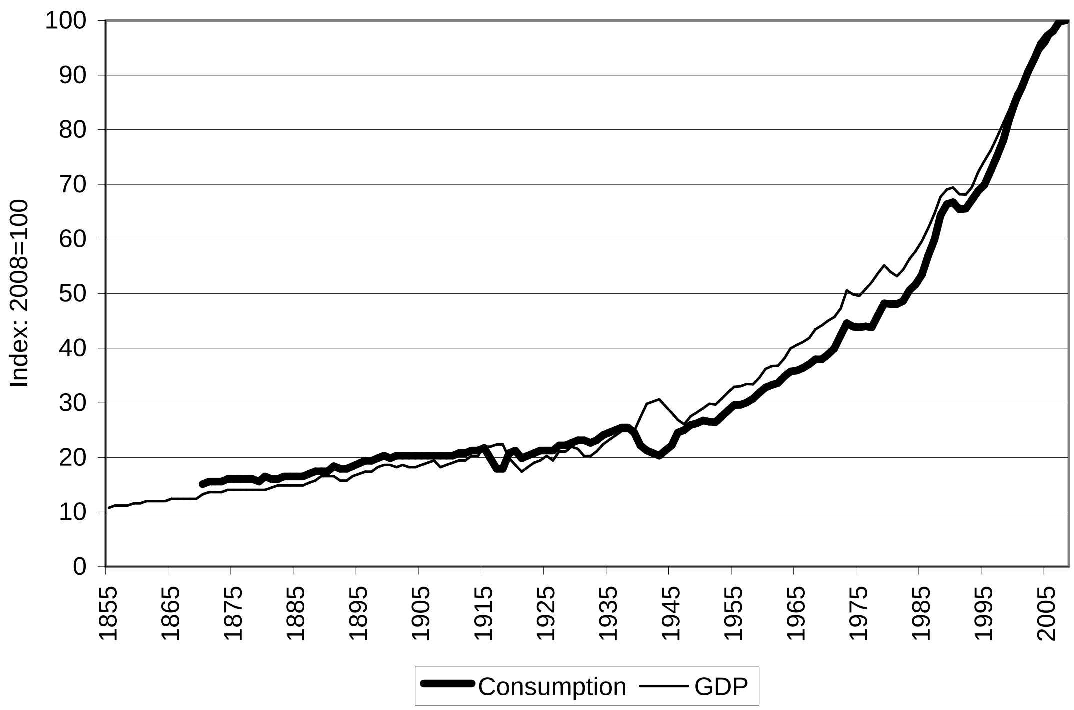


Source: ONS (2009b, series CDKO)

To compare income and expenditure over time it is essential to adjust for changes in prices. If income this year is, say, 2 percent higher than last year, and prices have stayed the same, then you are better off; and economists say real income has risen by 2 percent because you can buy 2 percent more. But if prices also rose by 2 percent, then you would not be better off as you could only buy the same as last year: real incomes would not have risen. In other words, if income or expenditure rise faster than prices, then they have risen in real terms.

From the mid-nineteenth century to the early twenty-first century, there has been incredible economic growth, howsoever it is measured. In real terms, GDP per head has increased tenfold since 1855; in the last fifty years, it has trebled. Real consumption per head has broadly followed (except, notably during the two World Wars). (Details Fig. 2.2.2.)

Fig. 2.2.2: Indices of real GDP and real consumer expenditure per capita: 1855 to 2008.



Sources:
GDP: only available from 1855: 1855-1947: Feinstein (1972, Table 42) 1948-2008: ONS (2007c, series IHXW).
Consumers’ expenditure: only available from 1870: 1870-1965: Feinstein (1972, Table 42)
1966-2006: derived from Feinstein (1972, Table 56); ONS (2007b, series ABJR) & ONS (2009a, Table 5.1).

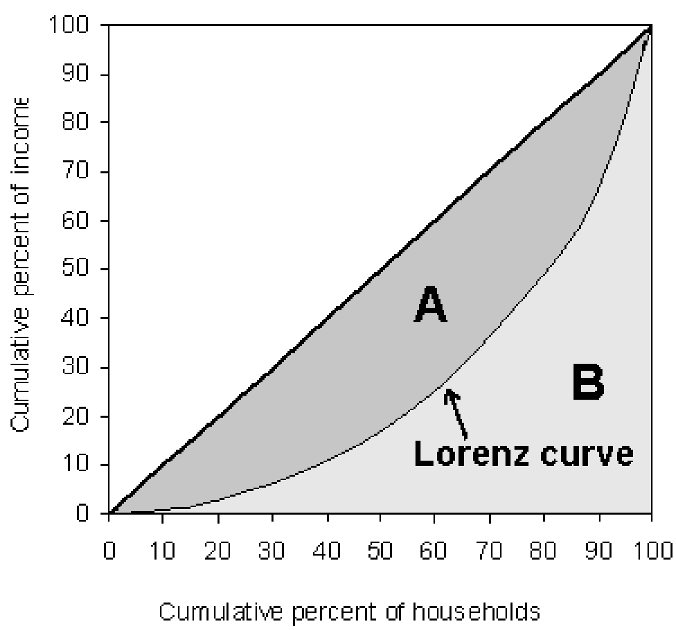
Not only has the 'standard of living' increased dramatically, but the distribution of incomes has also changed. This is important because a society with great inequality of income will have a different pattern of consumption from one with a more even distribution, other things being equal. As Deaton & Muellbauer (1985, p.370) pointed out, if incomes are very unequally distributed, diffusion of innovations will be slow. The degree of inequality in income distributions is measured by the Gini coefficient (explained in Box 2.2.1).

Box 2.2.1: The Gini coefficient.

If income were distributed evenly, then, for example, 50 percent of households would have 50 percent of the income. In practice, the distribution is skewed and the poorest half receive much less than half the income. Graphically, the income distribution can be represented by the Lorenz curve.

The Gini coefficient is the ratio of the area between the Lorenz curve and the straight line that represents an equal distribution (indicated by the darker shaded area A) and the total area below the line (area A + area B).

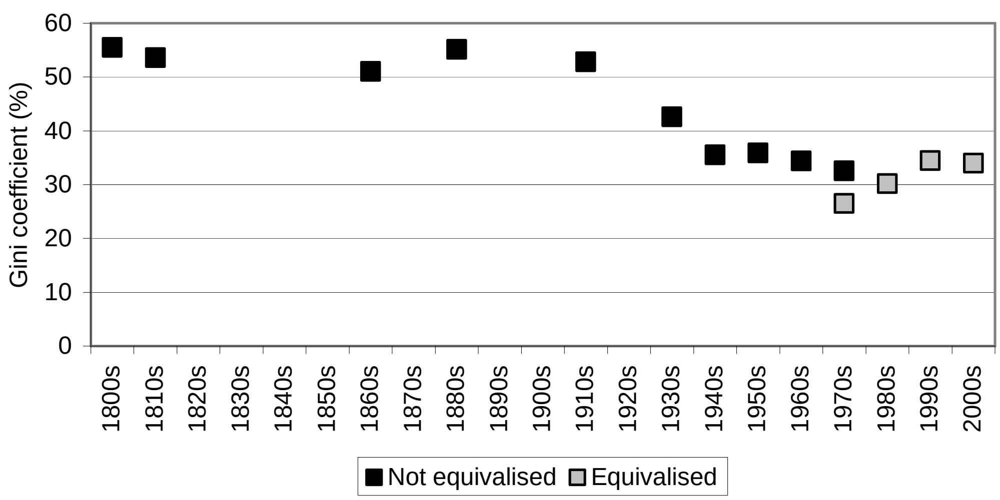
In other words, the Gini coefficient measures the extent to which the actual distribution of income deviates from complete income equality: the lower the coefficient, the more even the distribution.



It is, of course, difficult to calculate the Gini coefficient over a long time period but Fig. 2.2.3 summarises estimates from 1801 to 2007/8. Three distinct phases can be distinguished:

- From 1801 to the First World War, “the best conclusion one can draw from the very imperfect evidence is that the nineteenth century exhibited no marked fluctuations in inequality” (Feinstein, 1988). The Gini coefficient was around 50 to 55 percent (Soltow, 1980, p.61).
- From the First World War to 1981, there was a substantial decrease: the Gini coefficient fell from around 50 percent to 28 percent in 1981 (Soltow, 1980, p.61; Atkinson 2000, pp.362-366)
- During the 1980s, the Gini coefficient rose from 28 percent from 36 percent, since when it has fluctuated around 33 percent (Atkinson, 2000, pp.362-366; Barnard, 2009).

Fig. 2.2.3: Gini coefficients: 1801 to 2007/8.

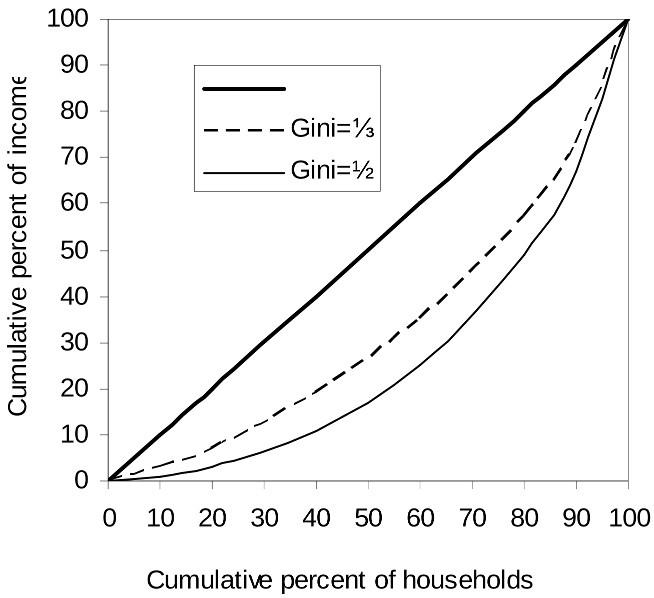


* Equivalised means that the income has been adjusted for the size and composition of households. Gini coefficients calculated on the basis of equivalised income are available from 1977: hence estimates on both bases are available for the 1970s.
Sources:
1800s to 1910s: Soltow (1980, p.60).
1930s to 1970s: Royal Commission (1980, Table 6.1).
1970s-2000s: Jones et al (2008).

Fig 2.2.4 shows what Gini coefficients mean in terms of the distribution of income. Two Lorenz curves for 2007-08 are shown:

- The solid line shows the Lorenz curve for original income (i.e. before taxes and benefits) with a Gini coefficient of 52 percent, about the same as it was in the nineteenth century.
- The broken line shows the Lorenz curve for disposable equivalent income (after tax and cash benefits but adjusted to allow for the fact that larger households need more income). This gives a lower Gini coefficient of 34 percent reflecting the equalising impact of taxes and benefits. Even with the lower coefficient, the bottom 40 percent of households receive only 20 percent of total income while the top 10 percent receive about a quarter of the income.

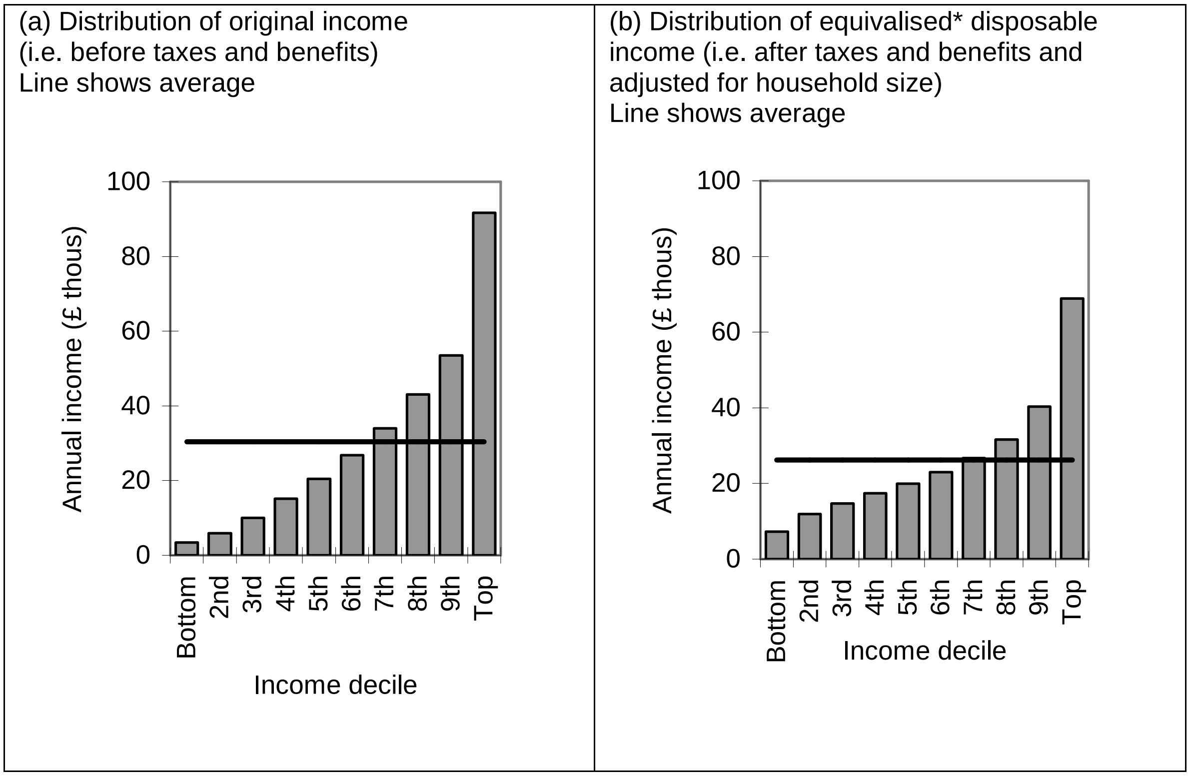
Fig. 2.2.4: Distribution of income: Lorenz curves for 2007-08.



Source: Barnard (2009, Tables 2 & 14).

Fig. 2.2.5 shows what these Gini coefficients mean in terms of the differences between the richest and poorest households: even with a Gini coefficient of about a third, and after adjusting for household size and composition, the incomes of the richest decile are 10 times larger on average than those of the poorest decile.

Fig. 2.2.5: Distribution of income by deciles based on equivalised disposable income: 2007-08.

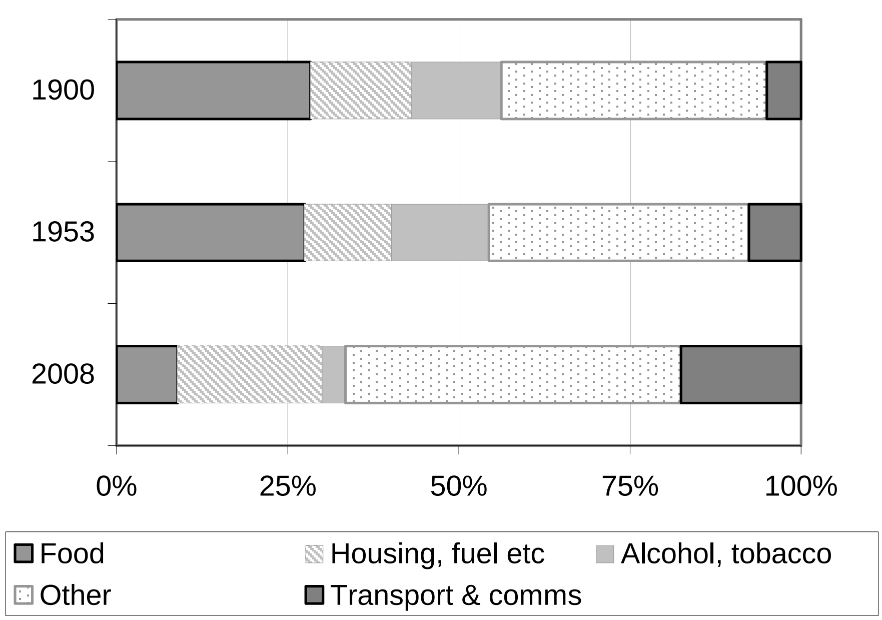


* Adjusted for household size and composition.

Source: Barnard (2009, Tables 2 & 14).

The pattern of consumption has changed as real incomes have risen. In the nineteenth century, the statistician C.L.E. Engel predicted that as income rises, the proportion spent on food would decline (Ferguson, 1969, pp.38-40). This is shown clearly in Fig. 2.2.6: in 1900, and still in 1953, food accounted for about a quarter of expenditure; by 2008, a tenth. Even more dramatically, the budget share of alcohol and tobacco has fallen from 13 percent to 3 percent. Rowntree (1902, pp.142-3) reported that "the average family expenditure of the working classes on intoxicants" was one sixth of "average total family income". This was, he claimed, the main cause of "secondary poverty", where earnings would be sufficient for "the maintenance of merely physical efficiency were it not that some portion of it is absorbed by other expenditure" (ibid, pp.86-7). In contrast, the budget share of transport and communications has increased: from 5 percent in 1900 to 18 percent in 2008. By 1965 economic growth and a more even distribution of income meant that "spending habits" were closer to those of middle-class Victorians (with the exception of domestic help and private educational expenses) (Burnett, 1969, pp.318-9). Analysis of UK expenditure data from 1900 to 1970 suggested that by 1963 "food, housing, travel and communication, entertainment, and services were necessities while clothing, fuel, drink and tobacco and other goods were luxuries" (Deaton and Muellbauer, 1985, pp.70-72).

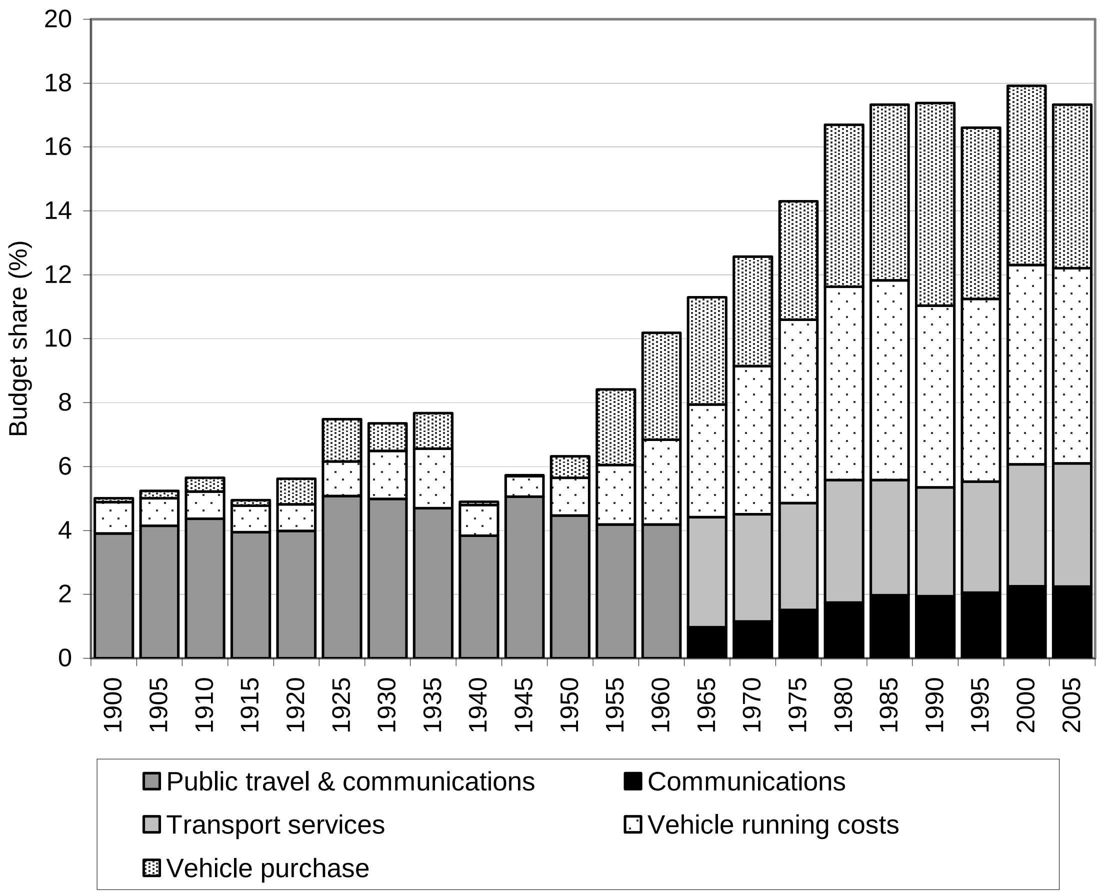
Fig. 2.2.6: Budget shares: 1900, 1953 and 2008.



Sources: 1900 and 1953: Feinstein (1972); 2008: ONS (2009c).

The increase in the share of transport and communications is almost entirely due to the increase in vehicle purchase and running, as shown in Fig. 2.2.7. Up to 1963-4, expenditure on communications, defined as "postage, telephone and telegraph" was combined with expenditure on public transport (Feinstein, 1972). Since 1963-4, communications, defined as postal services, phone and fax services and equipment but excluding "information processing equipment" has been separately identified (ONS, 2009c). On this basis, the share of communications rose from 1 to 2 percent between 1963 and 2008.

Fig. 2.2.7: Budget shares of transport and communications: 1900-2005.



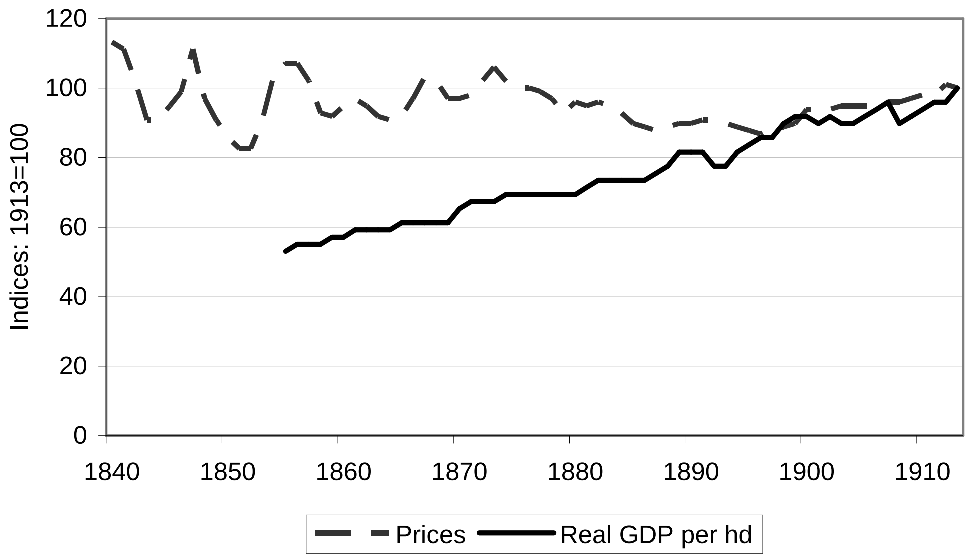
Sources: 1900-1960: Feinstein (1972, Table 24). 1965-2005: ONS (2009c).
Notes: Separate data for communications and public travel/transport services not available for earlier years.
To 1963-4: Three groups are identified (Feinstein, 1972, Table 24):
"Public travel and communications: railways, buses and coaches, taxis and carriages, tramways, air and sea travel; postage, telephone and telegraph"
"Vehicle running costs: petrol and oil, spare parts, garage costs, repairs, licences, insurance and other running expenses of motor cars and motor cycles; oats and other running expenses of carriages"
"Motor cars and motor cycles: new and secondhand"
From 1963-64: Purchase of cars, motorbikes and bicycles
"Operation of personal transport equipment" i.e. motor vehicle spares maintenance and repair etc, vehicle fuels etc.
"Transport services": road, rail, air, sea, inland waterways and "other purchased transport".

The rest of this Section discusses income and expenditure in three periods: 1840 to 1913, 1914 to 1945 and 1946 to the present.

1840 to 1913

Fig. 2.2.8 shows that by the start of the First World War prices were lower than at times in the middle of the nineteenth century, but "living standards" more than doubled over the period (due to the doubling of real wages (Boyer, 2000, pp.280-4, Table 11.2)).

Fig. 2.2.8: Real GDP per capita and prices: 1840-1913.

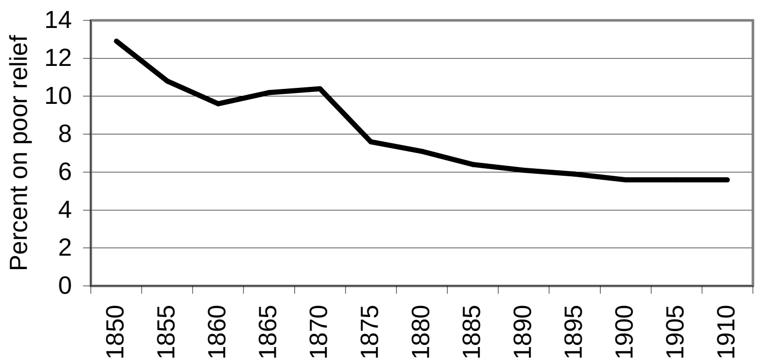


Sources: Prices: ONS (2009b, series CDKO). GDP: Feinstein (1972, Table 42)

At the start of the twentieth century, about two-thirds of the average budget was spent on the basics (food, housing, fuel and light, alcohol and tobacco, clothing) and only about 5 percent on travel and communications (Fig. 2.2.6.). However, between 1900 and 1913, real per capita expenditure on public travel and communications rose by 21 percent compared to 7 percent for total consumer expenditure (Feinstein, 1972, Tables 24 & 25; Mitchell, 1988, Table 3). But this data is limited in two ways. First, it presents an average. Second, it does not provide information before 1900. Data from ad hoc sources have to be used to provide more details. Below, evidence on the distribution of incomes is examined, followed by information on budgets, with particular reference to expenditure on communications and travel.

As was noted above, there was probably little overall change in the distribution of income over this period. Burnett (1969, p.247) reckoned that the "working class" comprised "rather more" than 80 percent "at the start of the nineteenth century, rather less at the end". Between 1850 and 1870 "10 percent of the population was assisted by the poor law each year" and taken over a three year period, "as much as 25 percent of the population made use of the poor law" (Boyer, 2004, p.297). From 1870 to 1913 the "the percentage of the population on relief halved but it is not clear whether there was less poverty as there were changes in the administration and in the attitude to the workhouse among the working classes" (ibid). (Details in Fig. 2.2.9.)

Fig. 2.2.9: Percent on poor relief: 1850-1910.



Source: Boyer (2004, p.297).

Ad hoc survey data provides further evidence:

- Allen (2009, pp.35-42) defined two baskets of goods based on calorie intake: "substistence" and the more expensive, "respectable". He reported that in London in 1825, typical labourers' incomes were about 30 percent above the respectability level but by 1875, were some 90 percent higher (ibid).
- In 1867 about 20 percent of families had an income of over £100 a year, then considered the minimum for the middle class (Beeton, 1859/1986, p.8; Picard, 2005, p.117). (Details in Table 2.2.1(a).)

- In 1892 Booth estimated that

  "8.4 percent of London's population was very poor and 22.3 percent was poor… representing 30.7 percent of the population and 37.4 percent of the working class were living in poverty" (cited by Boyer, 2004, pp.299-300).

  - In 1899 Rowntree reckoned that about three-quarters of the population were working class and a quarter in "the servant-keeping class". Ten percent of the population of York were poor in that their income was "insufficient to obtain the minimum necessaries for the maintenance of merely physical efficiency" (Rowntree, 1902, pp.86 & 111). A further 18 percent were in "secondary poverty" (discussed above). Thus nearly 30 percent were considered to be in poverty. (Details in Table 2.2.1 (b).)

Table 2.2.1: Distribution of family incomes in 1867 and 1899.

(a) 1867

£ pa	Percent	Examples
20-45	13	Agricultural labourers
46-59	21	General labourers, police
60-72	26	Miners
73-99	19	Skilled workers, teachers
100-299	16	Clergymen, clerks, senior civil servants
Over 300	4	Engineers, solicitors, barristers
Total	100	

Source: Soltow (1980, p.59 (based on Baxter)); Mitchell (1988, Table 23).
To convert roughly to 2008 prices, multiply by 80 (ONS, 2009b: CDKO)

(b) 1899: York

Class	Family income pw	Percent
A	Under 18s (90p)	2.6
B	18s (90p) and under 21s (£1.05)	5.9
C	21s (£1.05) and under 30s (£1.50)	20.7
D	Over 30s (£1.50)	32.4
E	Female domestic servants	5.7
F	Servant-keeping class	28.8
G	In public institutions	3.9
	Total	100.0

Source: Rowntree (1902, pp.31 & 45)
To convert roughly to 2008 prices, multiply by 90 (ONS, 2009b: CDKO)

- Between 1909 and 1913, Pember Reeves (1913/1979) studied 31 pregnant working class wives in London. Their husbands were "somebody's labourer, mate or handyman" earning some £50 to £80 a year (ibid, pp.2, 42-43). By comparison, a "middle class comfortable man" had an income of £500 a year (ibid, p.23). She concluded that there were at least 8 million people – i.e. 20 percent of the 40 million people then in Britain – who were "underfed, under-housed and insufficiently clothed" (ibid, p.214).

- Between 1912 and 1914, studies in Northampton, Warrington, Reading, Stanley and Bolton recorded poverty rates of between 6 and 23 percent (Boyer, 2004, p.301).

In 1881 the British Association for the Advancement of Science made "what was probably the only attempt in the course of the century to estimate how wages as a whole were expended" (Burnett, 1969, pp.258-9) but it is not clear from the description exactly whose expenditure was covered. These figures suggest that food accounted for 45 percent and Burnett (1969, p.239) reported that "food was the principal expenditure of the nineteenth century middle class". Even by 1900, food accounted for a quarter of the average budget (see Fig. 2.2.6 above). The basics certainly accounted for most of working class budgets:

- For the 1840s, Burnett (1969, pp.262-264) gave three examples of working class budgets, albeit with warnings that they may not be typical: the basics of food, housing, fuel and light accounted for almost all the budgets and food alone accounted for between 60 and 80 percent of expenditure.
- "In 1903-04 the Board of Trade carried out the first ever cost of living enquiries, using a sample of agricultural labourers and urban workman's budgets". Food accounted for 75 percent (Burnett, 1969, p.265).
- In 1909-1913, Pember Reeves (1913/1979) found that nearly 90 percent of the typical budget of the working poor went on the basics of food, housing, fuel and light. In contrast, the average share was only half that amount (Fig. 2.2.6 above).

Burnett (1969, pp.216-7, 235 & 245) mentioned leisure travel for the middle and upper classes, and Rowntree noted that for the relatively well-off working class group D (see Table 2.2.1(b)): "it is a growing practice…to take a few days' summer holiday out of York" and even those who do not take a holiday "avail themselves of the cheap day and half-day excursions" run by the railway company during the "holiday week" (ibid, pp.76-

77). However, he noted that this may be more common in York than elsewhere because of the "large number of railways employés (sic) who have the advantage of cheap 'privilege' tickets" (ibid, p.77).

The working classes rarely spent on communications or travel. Indeed, in his 1899 survey of poverty in York, Rowntree's poverty line made no allowance:

> "for any expenditure other than that absolutely required…A family living upon this scale…must never spend a penny on railway fares or omnibus. They must never go into the country unless they walk… They must write no letters to absent children, for they cannot afford to pay the postage". (Rowntree, 1902, p.133).

There is only occasional mention of the purchase of stamps and stationery (ibid, pp.265 & 266). Pember Reeves (1913/1979, pp.40, 82-83 & 172-3) claimed that the working poor "never write, and there is no time and no money for visiting": expenditure on stamps and stationery was reported in just 2 of the 31 budgets.

At the start of the period the middle and upper classes, who accounted for around a fifth of the population, could afford to use communication and transport services. But by the end of the period a quarter could still not afford mail and rail services.

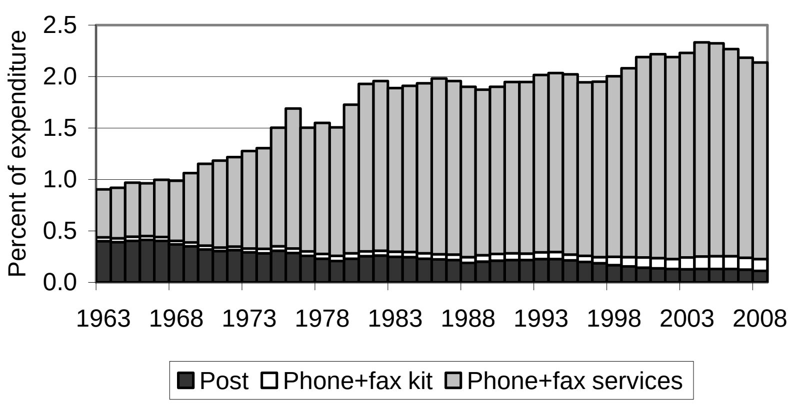
Two World Wars: 1914-1945

The third of a century from 1914 to 1945 spanned two world wars and a worldwide depression: it was by any account an unusual period and I do not propose to pay it much attention. But although consumption per head fell during the wars, in between it rose (see Fig 2.2.2 above). For example, real wages grew by 1.21 percent a year from 1913 to 1938, meaning that they increased by a third over the 25 years (1.021 raised to the power of 25: Boyer (2004, p.284) reporting Feinstein's calculations). It appears that the hardship caused by unemployment was partly alleviated by the social security system so that poverty rates were lower than before the First World War (Boyer, 2004, pp.299-303).

1946 to the present

Since the Second World War, consumption per head has risen steadily and (almost) continuously, quadrupling over the 60 or so years (see Fig. 2.2.2). Rationing ended in 1951. By 1953, the Ministry of Labour (1957, p.1) considered that "the pattern of expenditure was sufficiently stable to justify the holding of a new full-scale household expenditure enquiry". As noted above, in 1953 the overall pattern of spending was not very different from that in 1900 in that food, housing, fuel, alcohol and tobacco still accounted for just over half of budgets (Fig. 2.2.6 above). The Ministry of Labour's 1953/4 study showed that transport accounted for roughly 7 percent of expenditure, and communications for a little under 1 percent compared to 5 percent for both in 1900. Between 1959 and 1963, communications remained at about 0.7 percent of budgets and transport was around 10 percent according to expenditure survey data (Ministry of Labour, 1965). Using aggregate data, by 1963 expenditure on communications had risen to almost 1 percent of total expenditure; by 2008, it was just over 2 percent and was increasingly dominated by phones. (Details in Fig. 2.2.10.)

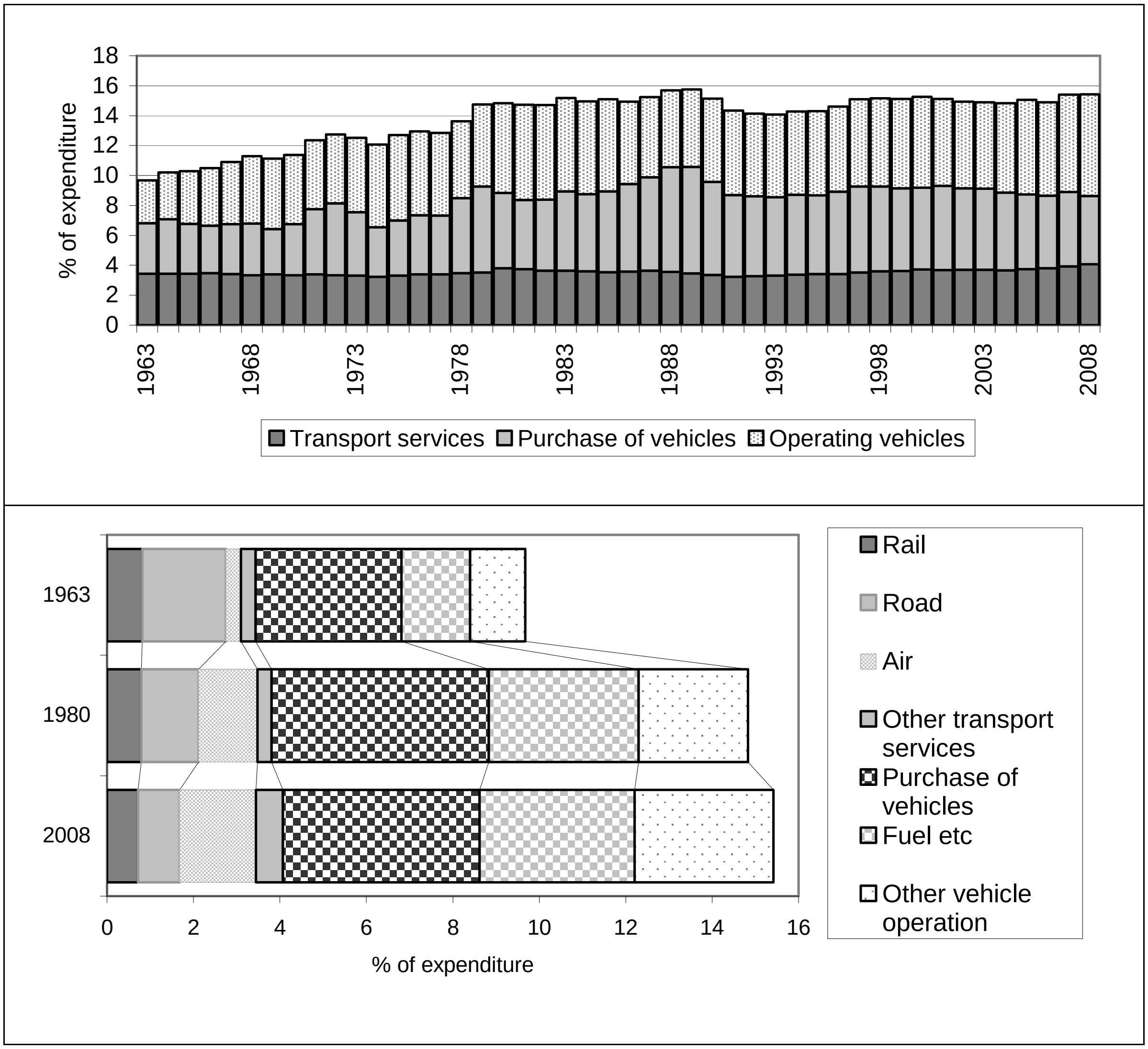
Fig. 2.2.10: Consumers' expenditure on communications by mode: postal, phone and fax services as a percent of total expenditure: 1963-2008.



Source: ONS (2009c: series CCVS, ZAWX, ATMR, & ZAKV)

Between 1963 and 1980, transport's share of total expenditure rose from 10 percent to around 15 percent, where it has remained. The growth was been entirely due to the buying and running of vehicles. However, while the share of "transport services" has changed little, there has been a switch from road to air with the share of rail services unchanged (Fig. 2.2.11).

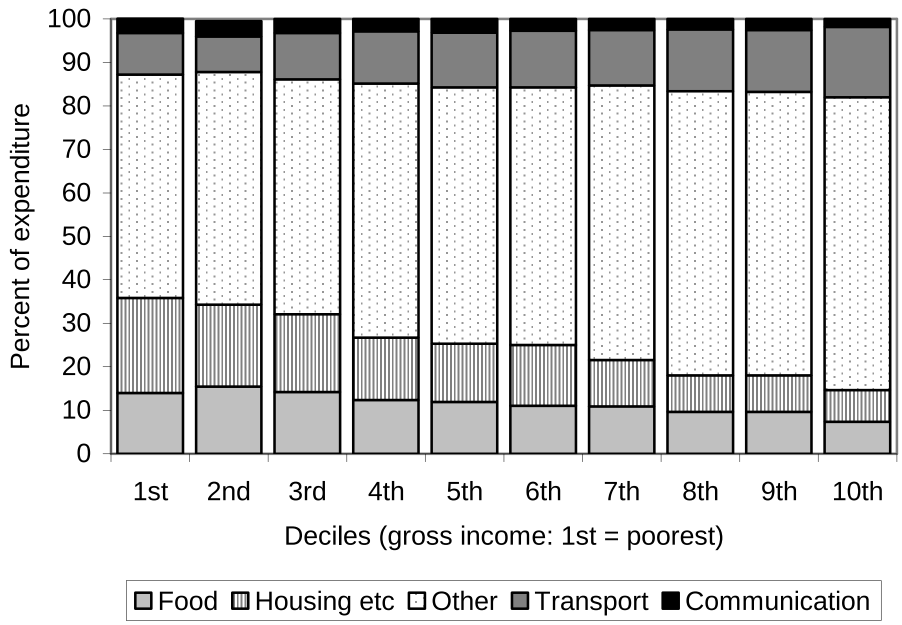
Fig. 2.2.11: Consumers' expenditure on transport as a percent of total expenditure: 1963-2008.



Source: ONS 2009c: (a) series ZAWR, TMMH, ZAWN & ZAKV (b) also series CCSC, ZAWT, AWUJ, AWUK

But these averages still hide differences between the richest and poorest households. In 1965, food, housing, fuel, light and power accounted for some 60 percent of manual workers' budgets but only about a third of the budgets of the richest households (Burnett, 1969, pp.319-20). The expenditure pattern still varied by income in 2007 although food, housing, fuel and power together only accounted for about a third of the poorest households' budgets and under a fifth of those of the richest. (Details in Fig. 2.2.12.)

Fig. 2.2.12: Expenditure pattern by gross income decile: UK: 2007.

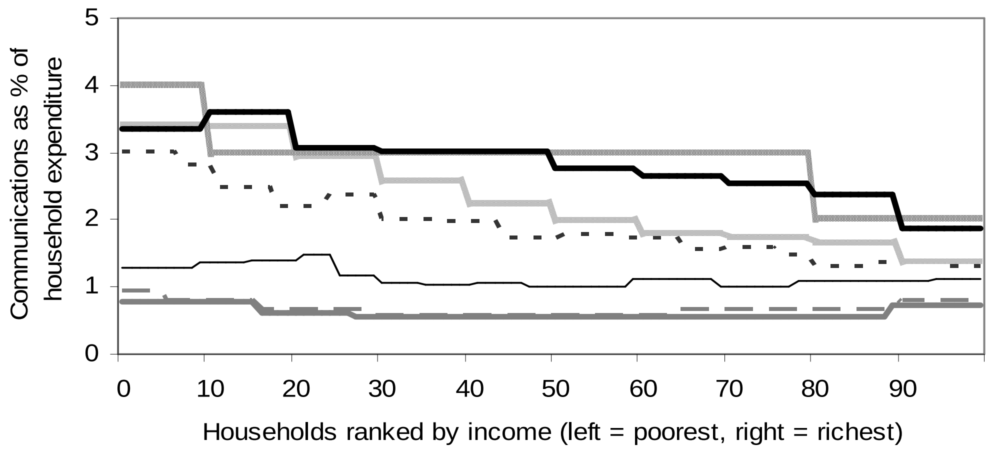


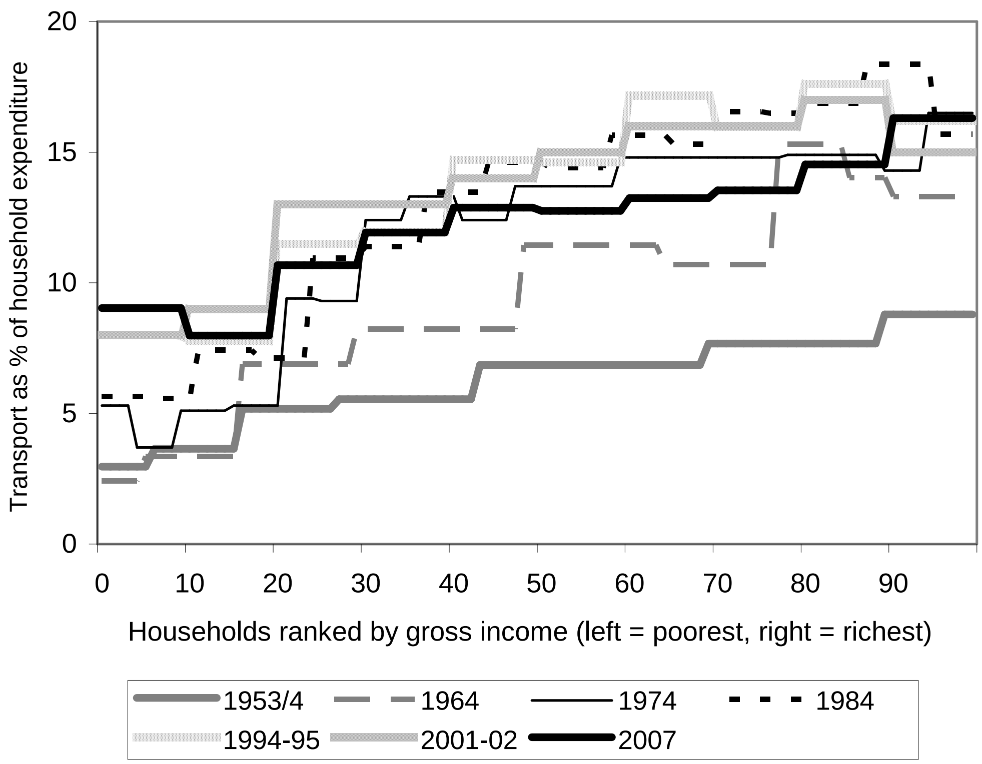
Source: ONS (2008a, Table A7).

Fig. 2.2.13 shows that the proportions of budgets spent on communications and transport have risen across all income groups since the 1950s. However, in the 1950s and 1960s, the proportion of budgets spent on communications did not vary by income, being under 1 percent for all income groups. But since the mid-1980s, poorer households have spent a slightly higher proportion of their budgets on communications than better off households. By 2007, communications accounted for 3.4 percent of the expenditure of the poorest households and only 1.9 percent of the richest (top panel). In contrast, the budget share for transport rises with income (bottom panel). In 1953-4, transport accounted for only 3 percent of the weekly expenditure of the poorest households but 9 percent of the richest households. By 2007, the poorest households spent 9 percent of their budget on transport, and the richest, 16 percent. Almost all types of transport expenditure rise with income, the notable exception being bus and coach fares but these account for only about ¼ percent of expenditure overall.

Economists distinguish between necessities and luxuries on the basis of how people change their expenditure in response to changes in incomes. If income rises by, say, 10 percent and demand rises by more than 10 percent the good is said to be a luxury; the income elasticity exceeds 1. If demand rises by less than 10 percent, the good is a necessity; the income elasticity is less than 1. Thus Fig. 2.2.13 suggests that communications are likely to be necessities because they take a greater share of the budget of poorer households, while transport is more of a luxury because its budget share rises with incomes.

Fig. 2.2.13: Budget share of (a) communications and (b) transport by household income: 1953-4 to 2007.





Sources: Ministry of Labour (1957, 1965); Dept of Employment (1975 & 1986); Central Statistical Office (CSO) (1995), ONS (2003a) & ONS (2008a).
Note: Definition C20th figures may vary from C21st figures.

2.3 Communications and Transport Expenditure

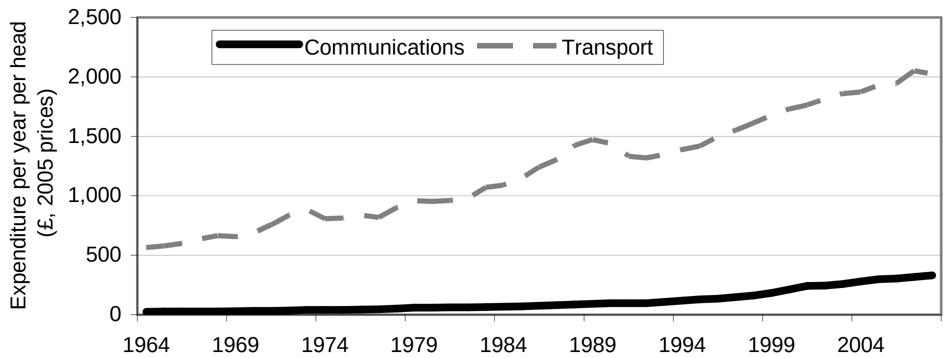
This Section primarily addresses the third question posed in the Introduction: how are expenditure on communications and travel related? But in doing so, it sheds further light on the question of the extent to which are communication and travel are necessities rather than luxuries. The Section opens with some simple analysis before discussing in more detail the relationship between expenditure on communications and travel.

Simple analysis

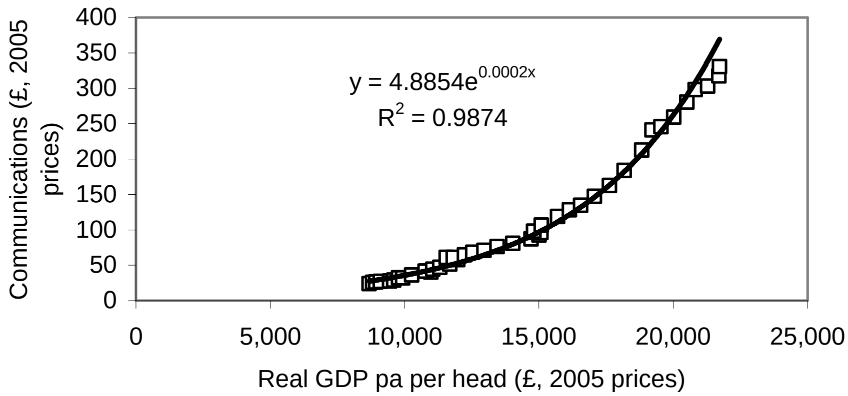
The simplest way to address the question of the relationship between expenditure on communications and transport is to look at how they have changed over time. Section 2 showed how the budget shares of both communications and transport increased. This implies that expenditure on communications and transport increased faster than total expenditure. In 1964 the average expenditure per head (in 2005 prices) on communications was £24 a year and on transport, £564: by 2008, it was £330 and £2,064 respectively. In other words, in real terms (i.e. excluding the effect of inflation as explained in Section 2), per capita expenditure on communications increased more than tenfold and on transport, almost quadrupled (as shown in the top panel of Fig. 2.3.1). By comparison, total real consumption per head almost trebled (see Fig. 2.2.2).

The middle panel of Fig. 2.3.1 shows how real per capita expenditure on communications is rising exponentially with real per capita GDP (which is a proxy for income). In contrast, the graph for transport expenditure, shown in the bottom panel of Fig. 2.3.1, shows a linear relationship. The rise in expenditure on both communications and transport as incomes have risen hints that they are complements rather than substitutes; and the rise in both as total real income has risen suggests they are luxuries rather than necessities. But more sophisticated econometric analysis is needed and this is reviewed next.

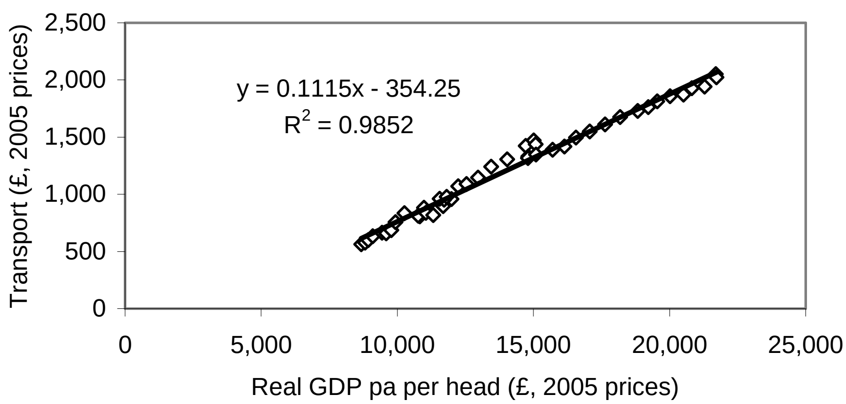
Fig. 2.3.1: Real consumers' expenditure per head on communications and on transport: UK: 1964-2008.



(a) Real expenditure on communication pa per head



(b) Real expenditure on transport pa per head



Sources: ONS (2009 series: ZAWM, ZAWW, DYAY& IXHW.).

Prices, substitutes and complements

The demand for a good or service depends on incomes as discussed at the end of the previous Section. It also depends on price. The price is often obvious; for example, for services paid on a per use basis, such as public transport fares. But in some cases identifying the price is not so simple. For example, equipment may have to be purchased, such as a car and so the price of a car journey is both the cost of the car and the running costs such as fuel. Or a subscription may be payable as well as paying each time that service is used; and different prices may be charged for different types of service. All four elements may be present in the case of phones: equipment, subscription, and varying charge per use.

In general, the higher the price, the less people will buy. If the price rises by, say, 10 percent and demand falls by less than 10 percent then demand is said to be price inelastic: the item's own-price elasticity is between zero and minus 1. People will try to maintain their expenditure on such goods even if they have to cut other expenditure to remain within their budgets.

Econometric analysis using aggregate consumer expenditure data is used to estimate price elasticities. Unfortunately, transport and communications are often treated as one item in these analyses. For example:

- Using UK data for 1900 to 1970, Deaton (1974, and Deaton & Muellbauer, 1985, pp.70-1) found that 'transport and communications' was a necessity in 1963: the own price elasticity was –0.5.
- Using British data from 1954 to 1974, Deaton & Muellbauer (1980, Table 2; 1985, pp.75-8) found that 'transport and communications' was a luxury with a high own price elasticity, exceeding –1 (the precise number varying with the method).

But as shown in the previous Section, the expenditure group 'transport and communications' will be dominated by transport and in particular, by spending on private vehicles, which has quite a different relationship to incomes than communications. I have found no studies focusing only on communications but there have been many attempts to estimate the price and income elasticities of transport. Oum & Waters (2000) pointed out that there are many different price elasticities, short-term or long-term, for transport as a whole and for specific modes or types of travel, such as business or leisure, and the values of the elasticities will vary accordingly. They reported a wide range of results for the own-price elasticities of travel ranging from –0.3 for transit systems off-peak to –4.6 for holiday air travel i.e. the demand for local public transport is not very price sensitive while that for holidays is very sensitive to price. Looking specifically at car travel, Graham & Glaister (2002, pp.94-95) surveyed "thousands of elasticity estimates" and found that car ownership is not very sensitive to either income or price in the short run, but was in the long run: for example the long-run income elasticity of car ownership was 0.7 and the long run own-price elasticity was –0.9. Furthermore, they reported that number of car trips and distance travelled are not very sensitive to fuel prices in the long term: the own price elasticity of fuel being –0.2 and the distance elasticity –0.3.

In some cases, the change in the price of one good will also affect the demand for another.

- If an increase in price of one good increases the demand for another, the two goods are said to be 'substitutes' and the cross-price elasticity is positive. Thus, for example, if the cost of a phone call rises, you may choose to write a letter instead and thus letters and phone calls are substitutes in the economic sense. Or if the cost of petrol rises and you decide to make a phone call rather than visit, then communication has substituted for travel.
- If an increase in the price of one good reduces the demand for both, they are 'complements' and the cross-price elasticity is negative. For example, if the cost of a rail journey rises then the demand for rail travel will fall and so will the demand for the bus service to the station: the rail trip and the bus journey are complements. Mokhtarian & Salomon (2002) suggested complementarity is more complicated to unravel than substitution because there are many different relationships possible between communications and travel. They identify the

> enhancement effect whereby for example more travel results in more use of a mobile phone or that keeping in contact results in visits. On the other hand, there is also an efficiency effect whereby communications are used to arrange meetings or to make better use of transport facilities.

Selvanathan & Selvanathan (1994) and Choo et al (2007) have attempted to unravel the relationship between expenditure on transport and communications using macro data: Selvanathan & Selvanathan used consumer expenditure data for the UK, and Choo et al used American data. Selvanathan & Selvanathan divided transport between public and “private” i.e. the “purchase and operation of motor vehicles” while Choo et al divided transport into three groups: vehicle purchase, vehicle operation and all other transport together with lodging away from home. Choo et al also divided communications between electronic and print. The results for income and own-price elasticities are shown in Table 2.3.1. Both studies show private transport to be a luxury and other types of transport a necessity, but they have different results for communications. According to Selvanathan & Selvanathan communications were a luxury. However, their data ended in 1986 and it was noted in Section 2 that only since the 1980s have poorer households spent proportionally more of their budgets on communications. According to Choo et al, using more recent data, communications are a necessity. The studies also differed in their findings on own-price elasticities. Selvanathan & Selvanathan found the own-price elasticity for communications to be very low and oddly, Choo et al found the own-price elasticity for vehicle purchase to be positive, implying that a rise in price increased demand. Overall Choo et al concluded that their results indicated that “communications expenditures are more essential than those for travel”.

Table 2.3.1: Estimated income and own price elasticities for transport and communications.

	Income elasticities		**Own price elasticities**	
	S&S (1994) (UK, 1960-1986)	**Choo et al (2007)** (US 1984-2002)	**S&S (1994)** (UK, 1960-1986)	**Choo et al (2007)** (US 1984-2002)
Private transport	2.1		-0.5	
- vehicle purchase		3.0		0.3
- vehicle operation		2.7		-0.4
Public/'other' transport	1.0	0.6	-0.4	-1.2
Communications	1.2		-0.1	
- electronic		0.9		-0.5
- print		0.2		-0.4

Sources: Selvanathan & Selvanathan (1994, Table 3); Choo et al (2007).

The results from both studies for the cross-price elasticities are shown in Table 2.3.2. Selvanathan & Selvanathan found that "public transport, private transport and communications are pair-wise substitutes", by which they mean that if the price of one increased, the demand for the other increased. Choo et al concluded that there was "a strong bi-directional feedback loop between travel and print communications with increased consumption of print media both generated by and generating, travel" and that "when electronic communications media costs decrease, consumers tend to increase their expenditures on purchasing cars". Choo et al concluded that "the dominant effect appears to be complementarity:…as telecommunications demand increases, travel demand increases".

Table 2.3.2: Cross-price elasticities between transport and communication.
(a) Selvanathan & Selvanathan (1994): UK, 1960- 1986.

	Private transport	**Public transport**	**Communication**
Private transport		0.1	0.1
Public transport	0.2		<0.1
Communication	0.6	0.1	

(b) Choo et al (2007): US 1984 to 2002.

	Transport			**Communications**	
	Non-PV	**PV (capital)**	**PV operation**	**Electronic**	**Print**
Transport: Non-PV	**-1.2**	1.5	1.3	0.3	1.2
Transport: PV (capital)	1.2	**0.3**	-0.1	-1.9	1.1
Transport: PV operation	-0.4	<0.1	**-0.4**	0.2	-1.2
Comms: electronic	**0.5**	**0.3**	**0.3**	**-0.5**	-0.2
Comms: print	**-1.5**	**<0.1**	**-0.5**	1.3	**-0.4**

Sources Selvanathan & Selvanathan (1994, Table 3): Choo et al (2007). PV = "personal vehicle"

Mokhtarian & Salomon (2002), Choo et al (2007) and Wang & Law (2007) all noted that micro-scale studies on the relationship between communication and travel have in the past tended to find that communications and travel are substitutes, although more recent micro studies together with long-term macro-level studies have suggested they are complements. For example, using 2002 data from Hong Kong, Wang & Law (2007) found "further evidence on the complementarity effects of ICT on travel, suggesting that the wide application of ICT probably leads to more, not less, travel". It is not clear whether the later studies have produced different results because they have used better methodology or because the relationship has changed. The overall view – Mokhtarian & Salomon (2002), Plaut (2004), Choo et al (2007) and Wang & Law (2007) – is that the relationship between communication and travel is complementary.

2.4 Conclusion

This Chapter set out to address 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?

This Section suggests some answers.

Limited time and money?

Overall there has been a steady decline in time spent working, leaving more time for leisure. This perhaps explains why ‘time-using’ goods diffuse faster than ‘time-saving’ goods. The use of this free time has also changed, especially with the introduction of TV, and may be in the process of changing again with the arrival of the internet. It is, however, very difficult to measure the time spent communicating because of the way it is embedded in all activities. But the evidence suggests that people do not spend much time on technologically-mediated communication and that time is not in general a constraint on communicating. In contrast, time spent travelling has remained roughly constant for some 30 years.

While there will always be just 24 hours in a day, the availability of money, in the sense of real incomes, has increased tenfold in the period covered by this study. From 1840 to 1913 the standard of living doubled, but even by the end of the period there was significant poverty of a kind that is not seen in Britain today. During this period, roughly about a quarter could afford to use communication services or travel; but for a further quarter, such activity was only rarely, if ever, affordable. For the remainder, communication services and travel became increasingly affordable as the years passed. In 1953, the overall budget pattern was very similar to that seen before the First World War and by 1965 it was similar to that of middle class Victorians. By 2007, the poorest households had a similar pattern of expenditure to the richest in 1965. As provision of the basics has taken up a progressively lower proportion of income – now only about a quarter of budgets are spent on food, housing and fuel – there has been increasing scope for discretionary expenditure, and expenditure on communications and travel have risen. Yet communications still account for under 3 percent of expenditure although this percentage continues to rise. It is therefore difficult to argue that communications are constrained by lack of money today as there appears to be plenty of ‘slack’ discretionary expenditure to switch to communications if desired. However, transport presents a different picture. Transport has accounted for 15 percent of expenditure since 1980. Black (2001) argued that “the constraint on travel, particularly long distance travel, is usually money for most of us.”

With rising living standards, the consumption of both communication and travel services has risen. Communications remain a small part of household budgets. Also 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 spend communicating. And there is a willingness (noted by Harper, forthcoming) to continue to adopt new means of communication. So it appears that there is still scope for further increases in both time and money to be spent on communication. Travel, however, seems to have reached ‘saturation’ in terms of both time and money.

Necessities or luxuries?

In economic terms, a luxury is a good or service, the consumption of which increases when incomes rise. Over time, rising standards of living have meant that the poor in a subsequent era can consume things available only to the rich in a previous era. In effect, some of today’s luxuries become tomorrow’s necessities (Douglas & Isherwood, 1979 pp.99, 121-2): “the poor”, Douglas and Isherwood argued, are “periodicity-constrained” and have to spend more time doing chores while the rich can afford new technology to free them. Further, they proposed that:

> "Periodicities give a rough approximation to a major difference in the use between necessities and luxuries: future necessities in the present luxury class will be sets of goods with effective periodicity-relieving properties. A telephone is just such a good, allowing control over the timing or postponement of social events." (ibid p.122).

In a similar vein, Urry (2000, p.110) argued that money is time: it is "access to money which enables time to be put to good use".

In the nineteenth century, both communications and travel were luxuries. Both cross-section and time series data suggest that now communications are necessary while some travel, at least, remains a luxury.

Relationship between expenditure on communications and expenditure on travel?

Both micro and macro studies have tried to tease out whether communications and transport are substitutes or complements. While there is a popular perception that they are substitutes (see, for example, Plaut, 2004) the overall conclusion is that they are complements. This is underlined by the simple fact that expenditure on both communications and transport increase over time, suggesting they are complements in the economic sense. This issue is discussed further in Chapter 5.

Chapter 3: Networks

The study of networks is currently much in vogue in academia but interest in networks, under the name of graph theory, can be traced back to Euler in the eighteenth century (Calderelli, 2005, pp.17-20; Newman et al, 2006, pp.1-3). A network comprises nodes and links and the characteristics of those nodes and links determine the nature of the network. Nodes can be things or people and the links can be any relationship between the nodes. There are many ways of categorising networks. For example, Watts (2004a) distinguished between 'symbolic' networks, which can be thought of as "representations of abstract relations between discrete entities" and "'interactive' networks, whose links describe tangible interactions that are capable of transmitting information, influence or material".

This Chapter starts by discussing the differences between just three types of network: transport, communication and social. The second Section introduces network models and the extent to which they can be used to represent transport and communication networks. The last Section focuses on social networks and concludes by examining the extent to which the models introduced in Section 2 can be used to describe social networks.

3.1 Transport, Communication and Social Networks

In line with the Oxford Dictionary (2001), I use the term transport to refer to the movement of people and communications to refer to the movement of information. People move between places: information moves between people. Thus transport networks connect places while communication networks link people. Social networks link people, too, but in a different sense. This Section discusses these three types of network in turn.

Transport networks

The characteristics of transport networks and thus the metrics used to describe them differ between networks. Road networks can be accessed at many points, and the size of the road network is measured in terms of the length of roads, the links. A railway network can only be accessed at a limited number of points, the stations: and is described in terms of the number of its stations, nodes, and the length of its tracks, the links. A shipping or an airline network has even fewer access points, ports and airports respectively. But while ports and airports are nodes that exist physically, the routes do not: they are representations on a map of paths followed by ships and planes. Thus a shipping or airline network is measured in terms of the end points of the links, the number of ports or airports served, rather than the length of the routes. However, all transport networks provide the potential for, the possibility of, travel. So all transport networks can also be measured in terms of use: for instance, the number of vehicles or passengers using them during a certain period of time or the distances moved, such as passenger-miles.

Transport networks are developed by organisations, public or private, taking decisions to supply a service based on the anticipated demand. Thus transport links are generally built or created between centres of population. If a service is not used, the link will eventually be abandoned. If there is a demand for the service, the links may be expanded. But expansion takes time. For example, a railway company may have to acquire more rolling stock and employ more staff, and maybe even lay more track. Thus users determine the transport network, but only indirectly and in the long term. To the extent that people are travelling for social reasons, social networks can be said to determine transport networks indirectly and in the long term.

Communications networks

Communications and transport networks were once regarded as synonymous because the postal service enables communication through transport networks. The two started to diverge with the arrival of optical telegraphy in the 1790s and the difference increased with electrical telegraphy in the 1840s (Headrick, 2000, p.193; Ling & Yttri, 2002; Sterne, 2006, p.119).

But even electrical communications networks vary in their characteristics. The telegraph and fixed line phone networks comprise physical links. A fixed line phone network was recently described in terms of the number of exchanges and processor units, its nodes, and kilometres of copper wire and optical fibre, its links (BT, 2006). A mobile phone network can be measured by the number of base stations. These phone networks now permit access to the internet, which can be measured in terms of its “physical building blocks”, “the computers and communication systems” (Cabinet Office, 2009, p.7).

As with transport networks, the infrastructures of communication networks provide the potential for, the possibility of, the act of communication. Sterne (2006, p.127) distinguished between communications, the infrastructure, at the macro level and communication, as the interaction between individuals at the micro level. It is more common to describe phone networks – both fixed line and mobile – in terms of the number of subscribers; and the size of the internet in terms of the number of people online. The network metrics of the physical internet, based on the routers, has been shown to be quite different from those based on domains, representing use (Faloutsos et al, 1999). Indeed, computer-mediated communications create a “new geographical spaces” called cyberspace (Batty, 1997): “the notional environment in which communication over computer networks occurs” (Oxford Dictionary, 2001). More recently the Cabinet Office (2009, p.7) defined “cyber space” (sic) as “all forms of digital activity”. Cyberspace can therefore be seen as a communications network.

At the macro, physical level, the builders of communication networks do the same as the builders of transport networks in that they facilitate an activity. But in the case of communications, the links are made directly by people interacting: it is people who send letters for instance. This is clearer in the case of phones, where, at the local level, it is the users rather than the infrastructure owners who determine the network. For fixed-line phones, people subscribe and then a physical link is installed from the exchange to their home or office. This illustrates a key characteristic of electronic-based networks. No-one will subscribe to an electronic-based communication network unless they can use it to contact others who they know. Put plainly, there is no point having a phone if no-one you know has a phone. In contrast, the railway network can be used to visit a person with no expectation that the visit will be returned. Thus people can be said to shape communication networks in an immediate fashion that does not happen in transport networks.

Social networks

A social network is conceptually different to both transport and communication networks It is generally recognised that the idea of a social network can be traced back to Simmel. (See, for example, Wellman, 1988, pp.22-23.) Although the concept was used in various anthropological, sociological, and psychological studies, Bott was probably the first to use the term 'social network' in 1957 (Bott, 1957/1971, p.59). Boissevain (1974, pp.24-5) argued that the concept of a social network "provides us with a way of viewing social relations". Despite the obvious benefit of simplicity, reducing social relations to lines on a diagram in this way has attracted criticism (Emirbayer & Goodwin, 1994) and risks reification (Mitchell, 1974; Licoppe & Smoreda, 2005). There is indeed a danger that the underlying meaning can get lost in sophisticated representations and analyses. As Latour (2005, p.131) cautioned, a "network is a concept, not a thing out there. It is a tool to help describe something, not what is being described".

In a social network, the nodes are people and the links represent relationships between people. There are, of course, many different types of relationships between people and so there can be many different types of social networks, ranging, for example, from kinship and affection to business and political. But howsoever the links are defined, social networks emerge from interaction between people.

In a social network, there are no physical links other than those provided by the communications and transport networks. Durkheim (1897/2002, p.278) argued:

> "It is not true that society is made up only of individuals; it also includes material things, which play an essential role in common life. The social fact is sometimes so far materialized as to become an element of the external world. For instance, a definite type of architecture is a social phenomenon; but it is partially embodied in houses and buildings of all sorts which, once constructed, become autonomous realities, independent of individuals. It is the same with the avenues of communication and transportation."

As Sawyer (2005, p.221) put it, these physical communication and transport networks "always socially emerge from historical processes". Urry (2004a) asked "surely there are no social networks, only material systems that realize communications, movements and the 'occasioned encounters' that characterise networks?" And Castells et al (2007, p. 152) argued that the mobile handset "can be understood as a communication node – always attached to a person – of the social network".

Social networks are, however, more than transport or communications networks because much communication is face-to-face. In other words, the use of a communications network only reflects part of the underlying social network. It is therefore not true to say, as Onella et al (2007, p.24) did, that since a mobile phone network "is derived exclusively from one-to-one communication, it can be used as a proxy for the underlying human communication network at the societal level". Zhao & Elesh (2008) distinguished between co-location, which they defined as a spatial relationship achieved by using transport and communication networks, and co-presence that is a social relationship.

Furthermore, it is commonplace that we do not always have close communication with those who we think of as important in our lives yet we often communicate very frequently with those who are not. Wellman (1996) concluded that those with whom there is frequent contact are quite different from those with whom people are "intimate"; and Wetherell (1998) claimed "there is no association between frequency of contact and the strength of relationships". Thus Surra & Milardo (1991) distinguished between two overlapping networks:

- psychological networks comprising those people who are close or important and with whom there is considerable variability in the amount of interaction;
- interactive networks comprising those with whom one has routine, face-to-face interaction and include more acquaintances.

Discussion

The importance of the relationship between these three networks for understanding communication and travel patterns is now being acknowledged. Axhausen (2002) noted that the spatial and social structure of travellers' social networks had been overlooked in transport research adding that a better understanding:

> "is crucial for the assessment of the further dynamics of overall transport consumption. The locations of friends, family and colleagues decide the amount of miles travelled, especially for leisure".

This is important, Axhausen (2003) suggested, because

> "if the spatial spread of social networks has increased then a large share of the observed increase in leisure travel should be due to this trend. In the short term, one would expect leisure travel to be inelastic, as the social networks cannot be restructured quickly".

Examination of the relationship between social and transport networks and information and communication technologies is just starting to emerge (for example, Carrasco et al, 2008a, 2008b).

Social, communication and transport networks have very different characteristics. Furthermore, social networks shape communication networks and transport networks. In the case of communication networks, this relationship is direct: for transport networks, it is less direct. The relationship between the three types of network is not simple: indeed, Root (2000, p.439) talked about transport and communication modes creating complex, non-linear patterns that can create new social connections.

3.2 Modelling Networks

As explained, a network is comprised of nodes and links. The basic characteristics of a node are its degree of connectivity and clustering coefficient:

- A node's **degree of connectivity** is the number of links to or from the node. (Sometimes this is shortened to 'degree' and sometimes 'connectivity' (Newman et al, 2006, p.335). Furthermore, it is not to be confused with the degree of separation, which refers to path lengths, described below.)
- A node's **clustering coefficient** is the extent to which the nodes connected to it are in turn linked to each other (Scott, 1991, p.74). It is measured by the ratio of the actual number of links to the maximum possible number of links (Scott, 1991, p.74; Wasserman & Faust, 1994, pp.121 & 126). (Some call this density but here density is used as a network characteristic, described below.)

Clearly the number of possible links depends on the number of nodes in the network. If the network has n nodes, each can make $(n - 1)$ connections**.** So if a link from node A to node B counts as one link and from node B to node A as another, then in total there are $n(n - 1)$ **directed links**. (If n is very large, this approximates to n^2.) If, however, the link between nodes A and B is counted as just one link, there are $n(n - 1) / 2$ **undirected links**.

The basic characteristics of a network are size, density and path length.

- **Size** is measured by number of nodes or links (Calderelli, 2005, p.254; Scott, 1991 p78 & p105).
- **Whole network density** is the ratio of the actual number of links to the total possible (Bruggeman, 2008 p.135);
- **Path length** is the distance between a pair of nodes measured by the number of links between the pair, given that any node or link can only appear once in each path (Scott, 1991, p.71). The shortest path between any two nodes is called the 'degree of separation': if two nodes are directly connected, the degree of separation is one, if they are connected by one intermediary, it is two, and so on (e.g. Watts, 2004b p.102; Bruggeman, 2008, p.135).

An example of these measures are shown in Box 3.2.1. (For a technical presentation of the different kinds of networks, see Calderelli, 2005, pp.19-37 & 234-5.)

Box 3.2.1: Example of characteristics of nodes and networks.

Size and density

In the network illustrated, there are 9 nodes. There are therefore (9 x 8) / 2 = 36 possible links.

Of these, 12 links exist. So the **whole network density** is 12 / 36 = 0.33.

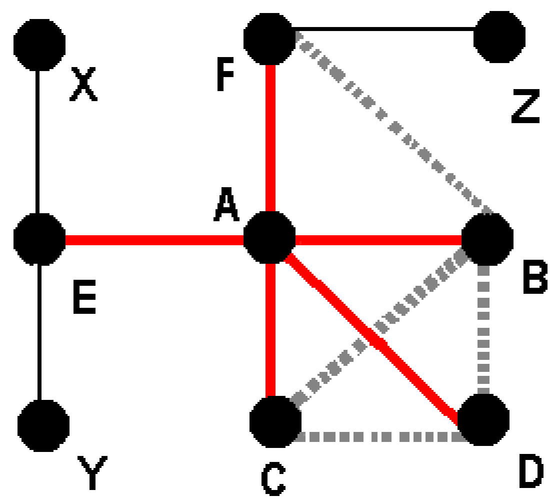
To calculate A's clustering coefficient

Node A's **degree of connectivity** is 5, as indicated by the thick solid (red) lines.

There are potentially (5 x 4) / 2 = 10 **undirected links** among A's network (excluding the links to A).

Of these 10 potential links, 4 exist,
- B to C, B to D, B to F and C to D -
as indicated by the thick broken (grey) lines and the X's in the matrix below.
Thus A's **clustering coefficient**
= 4 / 10 = 0.4.

	B	C	D	E	F
B		X	X		X
C			X		
D					
E					
F					



Path length

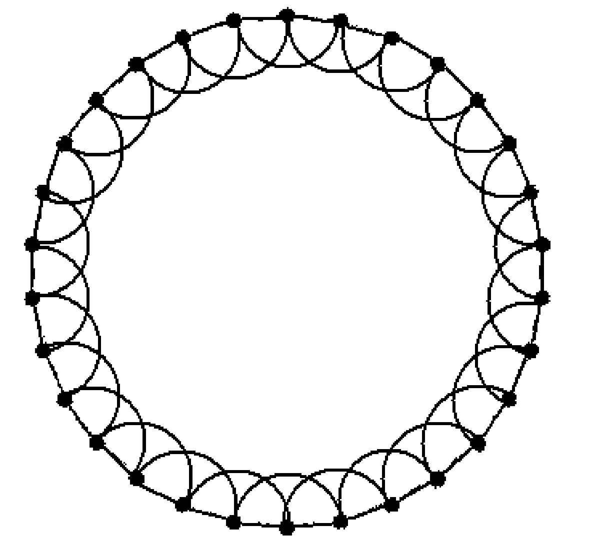
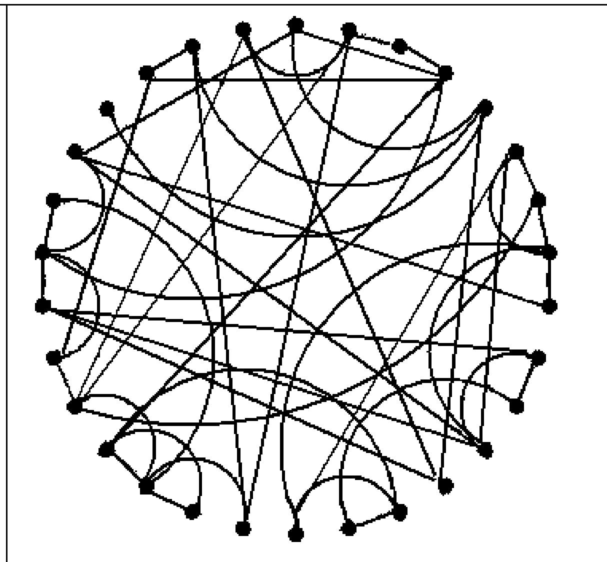
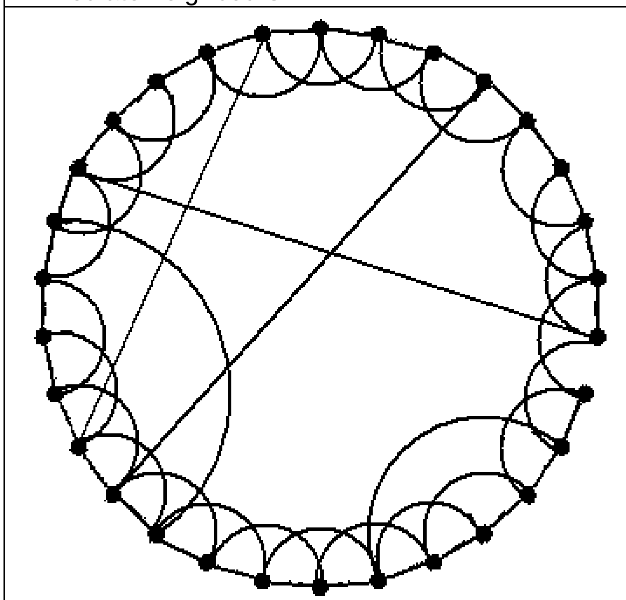
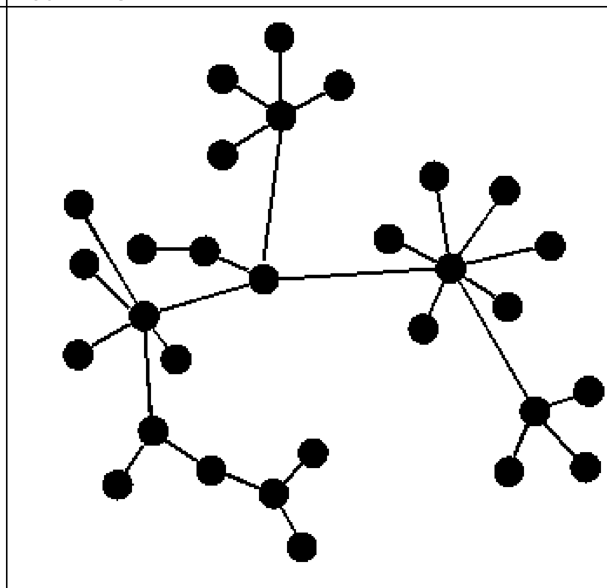
For example: the **degree of separation** between:

- node A and nodes B, C, D, E or F is 1 as they are all directly linked;
- node A and nodes X, Y, or Z is 2;
- node X and nodes B, C, D or F is 3;
- node X and node Z is 4: X to E, E to A, A to F and F to Z.

Four basic types of network model are found in the literature and Fig. 3.2.1 shows an example of each.

- The regular lattice, shown in panel (a), represents the simplest type of network and is often used in cellular automata models. Nodes are linked to their four immediate neighbours only.
- Random linking, shown in panel (b), has been analysed since the mid-twentieth century, starting with Erdős and Rényi (Newman et al, 2006, p.12). Most nodes will have approximately the same number of links and the degree of connectivity follows a Poisson distribution. Thus “it is extremely rare to find nodes that have a significantly more or fewer links than the average” (Barabàsi & Bonabeau, 2003). Path lengths are short (Pool & Kochen, 1978/9).
- The ‘small world’ network, shown in panel (c), is produced by a few random re-wirings of a regular lattice to produce a model with high clustering and short paths (Watts & Strogatz, 1998). In effect, the small world model inherits its clustering from the regular lattice and its short paths from the random model (Dorogovtsev & Mendes, 2003, p.105).
- The preferential attachment or scale-free network model, shown in panel (d), is created by new nodes tending to link to those that already have many links (Barabàsi & Albert, 1999), echoing what Merton (1968) termed the Matthew Effect or ‘the rich get richer’. This creates a hub-and-spoke pattern: many nodes have only one link and a few nodes have many links. The degree of connectivity follows a power law distribution. (It is because of the mathematical properties of power laws that the network is called ‘scale-free’.)

Fig. 3.2 1: Examples of four basic models of networks.
All with 30 nodes.

	
(a) Regular lattice: each node is linked to its four immediate neighbours.	(b) Random network: most nodes have three or four links.
	
(c) Small world network: most nodes are linked only to their immediate neighbours.	(d) Preferential attachment (scale-free) network: a few nodes have many links.

Generated using NetLogo (Wilensky, 2009).

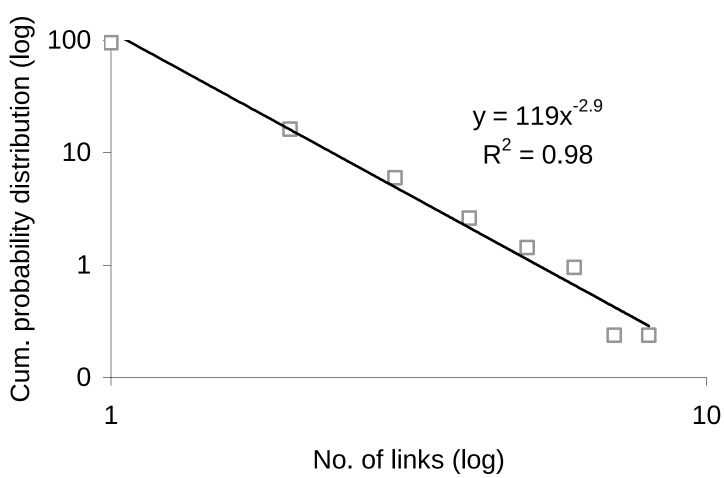
In theory, different types of network can be distinguished on basis of the distribution of their degrees of connectivity: a Gaussian (symmetrical) distribution is associated with a small world network, a Poisson distribution with a random network and a power law distribution with a preferential attachment network. It is, however, difficult to assess from real-life observations whether the distribution follows a power law. The easiest way to identify such a distribution is to plot the data against logarithmic scales and if the result is a straight line, then the distribution is probably a power law, although this cannot be guaranteed. (For a technical discussion, see Clauset et al, 2007.) Furthermore, it is clear that some distributions follow a power law function only in part. In particular, they are found to have fewer observations at the extremities than would be expected with a power law and they are described as truncated.

The rest of this Section looks at the extent to which transport and communication networks can be represented by these models. The next Section turns to social networks.

Transport networks

Looking at the physical structure of transport networks, Barabási & Bonabeau (2003) asserted that the US highway system is a random network because most nodes have roughly the same number of links. But this is probably due to the geography of the US. In Britain, major routes have focused on London since Roman times, giving a hub-and-spoke pattern, similar to those produced by a preferential attachment network. For the 420 railway stations in the south-east of England in 2005-06, I counted the number of links from each station using National Rail's (2008) maps. Fig. 3.2.2 shows that a power distribution fits well, suggesting that the preferential attachment model might represent it well.

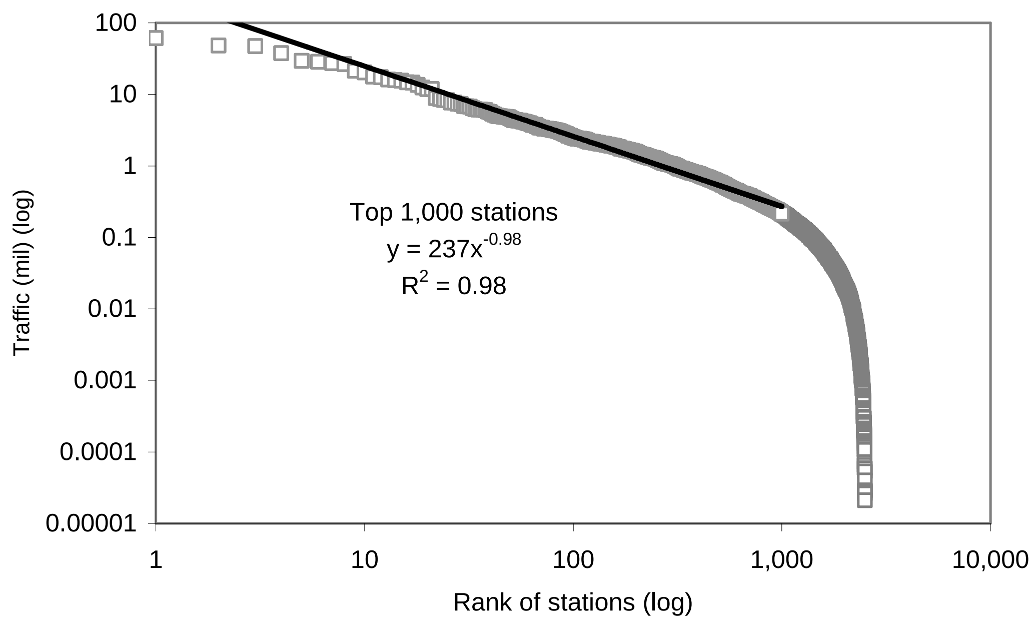
Fig. 3.2.2: Links at railway stations in south-east England: 2005-06.



Data source: National Rail (2008)

Using data on traffic at airports, Amaral et al (2000) found that there were "truncated scale-free networks, characterized by a connectivity distribution that has a power law regime followed by a sharp cutoff", due to, among other things the cost of adding links and the physical impossibility of having very large number of links. My analysis of traffic data for the 2,506 stations on the British railway network in 2005-06 produced a similar result, as shown in Fig 3.2.3. While traffic at the busiest 1,000 stations clearly follows a power law, this does not apply to the less busy stations: there is a sharp cut-off.

Fig. 3.2.3: Traffic at British railway stations: 2005-06.



Data source: Office of Rail Regulator (ORR) (2008)

Thus it appears that the standard network models can be applied to both the physical structure and use of transport systems.

Communications networks

Aiello et al's (2001) analysis of phone call data suggested that, at the very large scale, random patterns may appear. More recent work has suggested that a power law, with or without a cut-off, applies to communication networks too:

- the number of calls received by customers of AT&T's long distance telephone service in the US during a single day could be best described by a power law with a cut-off (Aiello et al, 2000; Clauset et al, 2007);
- Onnela et al (2007a) constructed "a connected network of 3.9 million nodes from mobile phone call records" that covered a fifth of a country for 126 days. They found that "in general, the degree distributions are skewed with a fat tail, indicating that while most users communicate with only a few individuals, a small minority talks with dozens";
- Lambiotte et al (2008) collected data on 2½ million mobile phone users in Belgium over 6 months and found that the distribution of degrees of connectivity followed a truncated power law distribution.

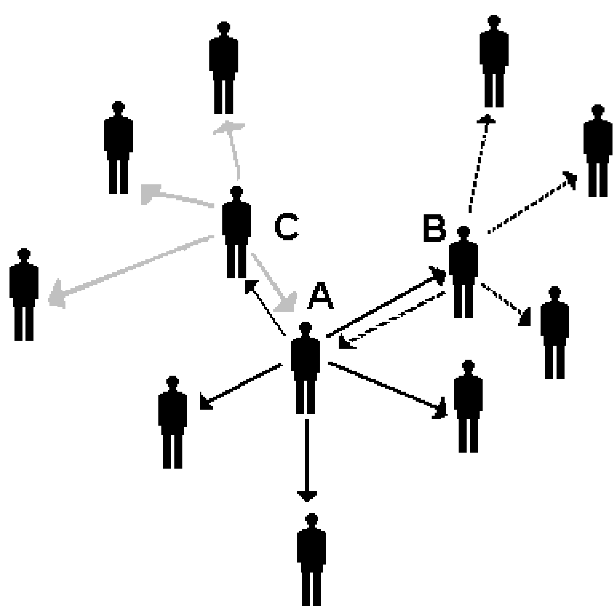
To the extent that communication networks reflect the underlying social networks, these findings suggest that social networks may be a sort of preferential attachment network. The next section turns to social networks.

3.3 Social Networks

Social network researchers face three levels of problems: defining what is to be measured, deciding how to measure it and who to include. To study a whole network requires defining the population, listing all the members and identifying all the ties. Such studies may be neither feasible nor appropriate (Wellman, 1988, p.26). Given these conceptual and practical problems, a more easily researched concept is a social network "centred upon an individual" i.e. all those who have ties with a specified individual. Such networks are variously called 'ego-centred' (Wasserman & Faust, 1994), 'personal communities' (e.g. Wellman, 1990; Suitor et al, 1997) or 'personal networks' (e.g. Grossetti, 2005). I will call them personal networks. According to Smoreda and Thomas (2001) a personal network is:

> "described by its size, its composition (family members, friends, acquaintances and colleagues, neighbours), its intensity (the frequency of interaction or the social distance among its members), its geographical range (members living in the vicinity, the same region, the same country or elsewhere abroad)".

Fig. 3.3.1: Personal networks.



To labour the difference between a social network and a personal network, Fig 3.3.1 shows three personal networks, of A, B and C respectively. The links are directional. A links to B and C; and B and C reciprocate. A's personal network does not show whether there are any links between A's links. However, combining all the personal networks of the 11 individuals illustrated would produce a complete set of relationships between all the members, a social network.

This Section looks first at the characteristics of personal networks then at those of social networks and concludes by identifying the key characteristics to be replicated in a model of a social network.

Characteristics of personal networks

The basic characteristics of personal networks are the characteristics of nodes, which following Section 2, are the degree of connectivity and the clustering coefficient.

The degree of connectivity is simply the size of a personal network and will depend on what relationships are used to draw up the network. The size of personal networks can vary from a few to thousands, depending on the type of relationships studied. Following Boissevain (1974, pp.47-8), five types of ties can be broadly defined:

- strongest: closest relatives and a few close friends;
- strong: emotionally important very close friends and relatives with whom relationships are actively maintained;
- medium: emotionally important very close friends and relatives with whom relations are passively maintained;
- weak: people who are important for their "economic and social purposes and the logistics of everyday life"(ibid);
- weakest: acquaintances, whose names may not be known.

Most researchers have focused on the stronger ties and depending on the definition used, these networks can range in size up to about 50 as shown in Table 3.3.1.

Table 3.3.1: Sizes of personal networks based on stronger ties.

Label	No.	Country	Notes	Source
“Confidants”	3	US		Marsden (1987)
“Intimate”	4-5	Canada		Wellman et al (1997), Mok et al (2007)
“Support clique”	5			Dunbar (1993 & 1998), Hill & Dunbar (2003)
“Close friends”	9	GB		Microsoft (2006)
“Personal cell”	10	Malta		Boissevain (1974)
“Friends”	9-11	US	Teenagers	Schiano et al (2002)
“Intimate”+ “significant”	11	Canada		Mok et al (forthcoming)
“Sympathy group”	10-15			Dunbar (1993 & 1998): Hill & Dunbar (2003)
“Core”	15	US	Median	Boase et al (2006)
“Interacted”	18	US	All interactions in last week	Vronay & Farnham (2000)
“Support group”	18.5	US		Fischer (1982)
“Active ties”	20	US/ W. Europe		Wetherell (1998)
“Core”	23	US	Average	Boase et al (2006)
“Close” & “somewhat close”	23	Canada	Average	Carrasco et al (2008b)
“Contacts”	20-30	GB	20-30s & >50s	Smith et al (2002)
“Personal” + “Intimate A”	30	Malta		Boissevain (1974)
“Core” + “Significant”	31	US	Median	Boase et al (2006)
“Band”	30-50			Dunbar (1993 & 1998): Hill & Dunbar (2003)
“Core” + “Significant”	40	US	Average	Boase et al (2006)
Instant messenger ‘buddy list”	50	Global	Average	Leskovec & Horvitz (2007)
“Friends”	54	GB	Includes kin	Microsoft (2006)

Dunbar (1993) argued that “there is a cognitive limit to the number of individuals with whom any one person can maintain stable relationships”, around 150, based on his study of primates. He cited many examples in both historical and modern societies and organisations. Some argue that Dunbar’s findings are not relevant to human societies because primates do not use spoken language, although Onnela et al (2007a) found some support for Dunbar’s number.

In contrast, the number of acquaintances could be in the thousands, as could the numbers of people ever known in a lifetime (Pool & Kochen, 1978/9; Marsden, 2005). Boissevain (1974, p.48) took a very broad definition to include people who his respondents “had met and had dealings with in the recent or distant past” and who “formed the social universe of persons who could help him solve his problems” (Boissevain, 1974, p.36). On this basis, the size of the personal networks ranged from 638 to 1,751 (ibid). Zheng et al (2006) estimated that the average total network size in the USA was 750 in 1998-9. Other estimates of total network size range from 200 to over 1,500, but it is not clear how 'network' has been defined (Wellman, 1990; Wetherell, 1998; Wellman & Gulia, 1999; Marsden, 2005). A selection of studies of wider personal networks are summarised in Table 3.2.2 using the five-zone framework.

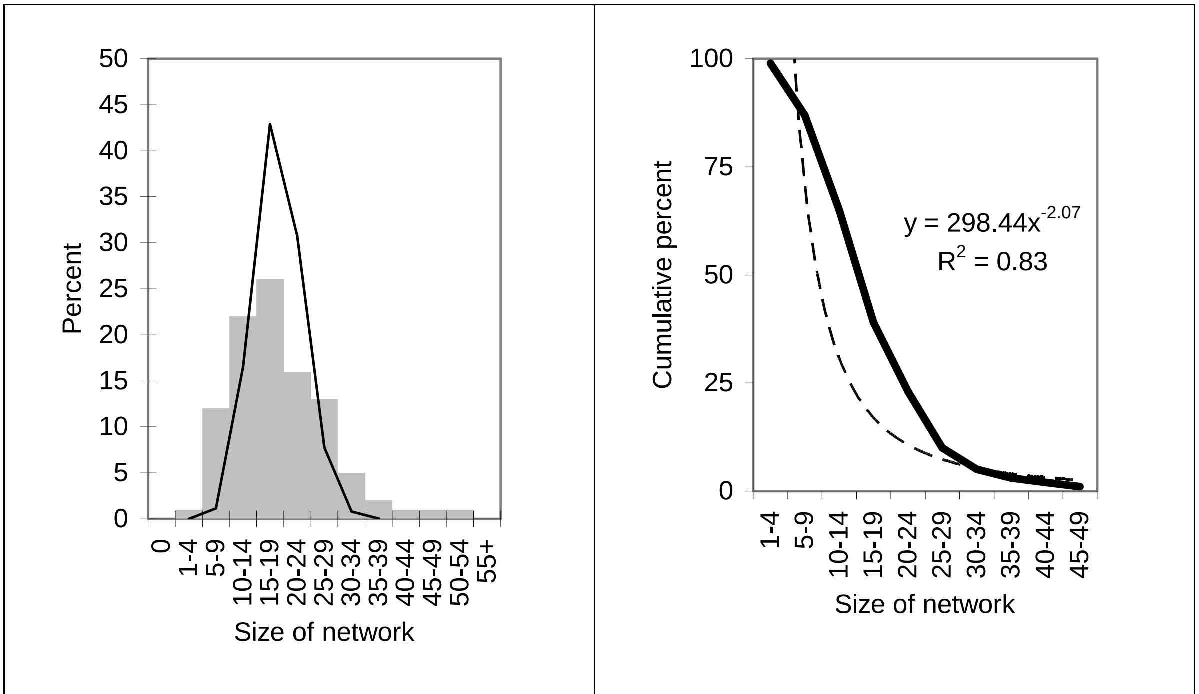
Table 3.3.2: Personal networks sizes by strength of tie.

	Boissevain (1974)	**Dunbar (1993 & 1998) & Hill & Dunbar (2003)**	**Wellman & Gulia (1999)**	**Boase et al (2006)**	**Summary**
Time	**1960s**	**Various**	**Various**	**2004**	
Place	**Malta**	**Various**	**Various**	**USA**	
Strongest	Personal zone: 10	Support clique: 5	Intimate: 6	Core: Median, 15. Average, 23	5
Strong		Sympathy group: 7	Signifi-cantly strong: 45		5-10
Medium	Intimate zone A: 20	Band: 23		Significant: Median, 16 Average, 27	20-30
Weak	Intimate zone B: 100	Cognitive group: 115 Maximum network: 153.5 (GB)	950+	Friends, relatives and acquaint-ances: 150	100-150
Weakest	Rest of social universe: 488-1,601	Mega-band: 350 Tribe:1,000			500-1,600
Total	600-1,750	1,500-2,000	Over 1,000		600-2,000

Note the figures used are not cumulative i.e. there are 10 in Boissevain's "personal zone" and another 20 in his "intimate zone A", giving a total of 30 in these two 'zones', which represent those with the strongest ties.

Howsoever defined, personal networks vary in size between individuals. Boissevain (1974, pp.124-5) noted the existence and importance of well-connected people, or 'stars' as Travers & Milgram (1969) called them. It is these few, well-connected people who cause the cumulative degree of connectivity to be 'fat-tailed' and follow a power law. But often researchers limit the number of names collected from their respondents and even when respondents are given full freedom, only summary statistics are reported. For example Boase (2008) found that the median number of active ties was 35 against a mean of 51, implying a right-skewed distribution. Thelwall (2008) found the median number friends on the social networking site *MySpace* in 2007 was 27 but some had over 90, approximately following a power law distribution. Fischer (1982, pp.38-9) found that while the average size of the personal networks in which he was interested was 18½, one individual had a network of 67. The left panel of Fig. 3.3.2 shows that compared to a Poisson distribution, which would suggest a random network, distribution of connectivity in Fischer's sample is positively skewed and has a fat-tail; while the right panel shows that although a power law fits the tail of Fischer's distribution well, it is not a particularly good fit overall.

Fig. 3.3.2: Fischer's distribution of personal networks.



(a) Compared to a Poisson distribution with the same mean (black line)	(b) Cumulative, fitted to a power distribution (dashed line)

Not all social networks can be fat-tailed, however. Bruggeman (2008, p.34) pointed out that "the distribution of close friendships cannot have a fat-tail". As Aristotle (c300BC/1996, Book 9: x, 3-6) noted, "the number of one's friends must be limited" because, in modern terminology, the maintenance of social networks is not costless

(Gilbert, 2006). Such costs result in cut-offs in real networks (Watts & Strogatz, 1998; Amaral et al, 2000; Barthélemy, 2003). Where those cut-offs fall depends on the type of network being modelled: the cut-off will be at a very small number if it is a network of 'confidants', with an average of two or three (Marsden, 1987) but for acquaintances, the number could be in the hundreds or even thousands as discussed. Thus any model should limit the size of personal networks because of the costs to individuals of maintaining them. But the model should also permit the size of personal networks to vary between individuals (unlike, for example, Watts et al, 2002) with the possibility, if required, of some individuals having much larger personal networks than average.

Kin represent a special subgroup within personal networks. But the concept of kin is fluid. Kinship groups are socially constructed: "social conventions" determine who are regarded as relatives and these vary between cultures (Zerubel, 2004, p.67). Furthermore, kinship does not necessarily imply a strong social relationship, although Microsoft (2006) reported that over a third of "Brits" regarded "their mum" as a close friend: and similarly for a brother or sister. Nevertheless, kin, howsoever defined, are often an important part of a person's social network and appear to account for about half of strong relationships (Wellman et al, 1997; Fischer, 1982; Morgan et al, 1997). Even among larger networks, kin may still form a significant group; Hill & Dunbar (2003) reported larger networks containing between 10 percent and 37½ percent kin. Kin networks also differ from non-kin because they tend to be more heterogeneous (McPherson et al, 2001).

Aristotle (c300BC/1996: Book 9: x, 3-6) also noted that "one's friends must also be friends of one another", implying that the clustering coefficient is high. More recently, Granovetter (1973) suggested that the stronger the ties the more similar people are. Indeed, homophily – the principle that contact between similar people occurs at a higher rate than among dissimilar people – is a key characteristic of social networks. McPherson et al (2001) reported that, in the US, race and ethnicity are the most important factors followed, in order, by "age, religion, education, occupation and gender". In analysis of social networks, the extent to which one's friends are also friends of each other is measured by the clustering coefficient while whole network density is the ratio of the actual number of links to the total possible in the social network. Rolfe (2004) reported a set of studies in which the clustering coefficient varied from 0.27 to 0.52. According to Scott (1991, pp.80-2) Wellman found that the mean clustering coefficient of the personal networks he studied – based on 6 named individuals – to be 0.33, although half were less than 0.25 and one in eight, over 0.75. Denser networks comprised a higher proportion of kin: three-quarters of the densest networks were kin (ibid). Fischer estimated the average clustering coefficient as 0.44 but ranging from zero to one (Fischer, 1982, p.145).

Characteristics of social networks

In Section 2, it was noted that networks have three basic characteristics: size, path length and density. The size of a social network depends on the group under study: it could vary from an extended family to a nation.

If everyone knew everyone else, then density would be equal to one. That may be the case in small communities, but it is clearly not the case in larger ones. Even if on average an individual knows, in some sense, a few thousand people, that is only a tiny fraction of the almost 7 billion people on the planet. Thus global density is low. Despite this low density, the 'small world effect' was first noted 80 years ago (Karithny, 1929/2006): i.e. that anyone in the world can be reached by a few steps. In network terminology, path lengths, the number of links between any pair of individuals, are short (Watts, 2004b, p.38).

Pool & Kochen (1978/9) argued, using a thought experiment, that if links were random, the small world phenomenon would rarely be observed, but when it was, the path length would be short, with only two links; in contrast, they suggested that Americans were linked by just seven intermediaries due to the structure of society, to the tendency of similar people to mix with other similar people i.e. to clustering. While there is abundant anecdotal evidence, scientifically-based evidence is thin.

- Milgram's famous experiment suggested that there were just "six degrees" of separation, although this is based on just 64 chains completed by middle-class Americans (Travers & Milgram, 1969). However, among Milgram's papers held at Yale there are details of an earlier, unpublished, study that he undertook, in which only three of the 60 chains (5%) were completed (Watts, 2004b, p.134; Kleinfield, 2002a, 2002b). Watts (2004b, p.134) reported that "only a handful of other researchers had attempted to replicate Milgram's findings, and their results were even less compelling than his".

- On the basis of a study undertaken between 2001 and 2003 using email, Dodds et al (2003a, 2003b) concluded that social searches can reach their targets in a median of five steps within countries and seven when the chain extends between countries. However, of the 24 thousand message chains initiated, just 384 were completed: that is, 1.6 percent. Dodds et al (2003) claimed that the main reason for chains failing to complete was due to random failure.

But as Watts (2004, p.136) pointed out, just because people cannot find a short path does not mean that it does not exist. Leskovec & Horvitz (2007) overcame the search problem by analysing communication links between 1,000 people globally, and found an average path length of 6.6 but a maximum of 29. However, as Dodds et al (2003a) reported "much about this 'small world' hypothesis is poorly understood and empirically unsubstantiated". Indeed, Liben-Nowell & Kleinberg's (2008) analysis of the progress of internet chain letters found that rather than spreading widely and reaching many people in a few steps, as the small-world model would suggest, they actually followed "a very deep, tree-like pattern, continuing for several hundred steps".

Recently Newman (2003; Newman & Park 2003; Newman et al 2006, p.555) suggested that a key feature of social networks that distinguishes them from other networks is the positive assortativity of the degree of connectivity i.e. those with many links link to others with many links. Bruggeman (2008, p.35) has suggested that positive assortativity is a type of homophily: sociable people like other sociable people. There does not appear to be agreement on how assortativity should be measured (see Newman, 2003). Newman (2002; 2003) devised an index that equals one when there is perfect assortativity and lies between zero and minus one when there is complete disassortativity: a random network, for example, would produce an assortativity index of zero. Applying his measure to datasets of coauthorships, film actor collaborations, company directors and email address books, Newman (2002) found that his assortativity index was positive; while for technological networks (such as power grids and the internet) and biological networks (such as food webs and neural networks) the index was negative. Onnela et al (2007a) also found evidence of positive assortativity in their study of mobile phone use. More work is needed to establish whether positive assortativity is indeed a feature of social networks. But if it is, then neither random nor preferential attachment network models provide this characteristic and so new models are required.

Dynamics

How do personal networks change over time? Boissevain (1974, p.48) suggests that "a person's network is a fluid, shifting concept". The size, structure and membership of a personal network will change over time, as the individual ages. For example, Grossetti (2005) reported "a constant turnover" in personal relationships: developing from family at birth though to friends at school, adding co-workers and neighbours in adulthood. Older people appear to have smaller networks than younger people, but this may be as a result of differences in definition, with older people less ready to define someone as a friend while teenagers seem to collect names, perhaps as a way of establishing their identity independent of their families. For example:

- Ling & Yttri (2002) reported that Norwegian teens had between 100 and 150 names in their mobile phones' address lists even though "many of the names were infrequently used".
- Smith et al (2002) found that British teenagers claimed a network of 70 contacts on average, much larger than other age groups studied, at least in part because they defined their networks more broadly.
- Fischer (1982, p.253) noted "The older respondents were, all else equal, …the smaller their networks".
- In Britain in 2000, those under 30 were more likely to report friends living nearby and report more friends than other age groups (Coulthard et al, 2000).

However, it is not clear to what extent the changes are due to ageing per se and to what extent to life events. Key life stage events, such as marriage, do affect the both the size and structure of the network (see Kalmijn, 2003 and Kalmijn & Vermunt, 2007). Matsuda (2005, p.136) noted that Japanese singles' personal networks concentrate on friends while those of married couples focus on relatives and neighbours. In Britain lone parents with dependent children are particularly likely to have daily contact with kin, friends and neighbours (Coulthard et al, 2002). Wellman et al (1997) suggested that it is the change in marital status that matters – be it marriage or divorce – rather than age.

As noted by McPherson et al (2001), longitudinal studies are rare. Morgan et al (1997) studied the personal networks of older widows over a year and found "a core set of ties", often kin, that were present at every interview plus "a peripheral set of ties" that appeared once or twice and tended not to be kin. Over 10 years, around a quarter of close ties persist (Wellman et al, 1997; Suitor & Keeton, 1997). It appears that there is a large turnover of members of a personal network, especially non-kin. Kin relationships are not easily broken and are likely to persist over time even if contact is infrequent and the social ties are weak. The structure also appears to be affected by changes in marital status, both marriage and divorce.

While the evidence on changing personal networks is sparse, it is clear that a good model of personal networks should allow them to change considerably over time.

Conclusion

Bruggeman (2008, p.36) listed seven key characteristics and Wong et al (2006) listed five, partly overlapping with Bruggeman's. Drawing on these, together with the above discussion and sometimes rather weak evidence, it appears that personal 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. members of an individual's personal network should tend to know each other to reflect homophily;
- change over time.

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 (although this may not be true for small, closed groups);
- 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 "highly connected within themselves but loosely connected to others" (Wong et al, 2006);
- short path lengths, i.e. others can be reached in a small number of steps.

How does this list compare with the four network models described in Section 2?

The regular lattice has limited personal network size, high clustering as many of one node's neighbours will also be neighbours of each other, and a low whole network density. But it fails to meet the other criteria and is therefore a poor model of a social network.

Random networks have limited personal network size and short paths (Dorogovtsev & Mendes, 2003, p105). But social networks are not in general created by making random links: rather, homophily dominates. So it is hardly surprising that random networks fail to replicate other key features of social networks. Indeed, the assortativity index of a random graph can be shown analytically to be zero (Newman, 2002). So random networks are not good models of social networks either.

The small-world model is closer to a social network than the regular lattice or random networks: it has high clustering and short paths. But it does not produce communities, nor nodes with high degrees of connectivity, nor display positive assortativity. Watts agreed: “the small-world model is not in general expected to be a very good model of real networks, including social networks” (Newman et al, 2006, p.292); and Crossley (2008) concurred.

The preferential attachment model can be criticised on the basis of its underlying dynamics. People do not usually know who has many links and even if they did would not necessarily want to link to these popular people, or the ‘target’ may not want to reciprocate. For instance, the failure of Milgram’s and subsequent small world experiments could be taken as evidence that people have only limited information about others’ connections (Travers & Milgram, 1969; Dodds et al, 2003). In their studies of sexual partners in Sweden Liljeros et al (2001) found evidence of people seeking out those with many links. As with the random network, the assortativity index of the preferential attachment model can be shown analytically to be zero (Newman 2002). But the preferential attachment model does produce low whole network density, a fat-tailed cumulative degree of connectivity and communities: and it can produce short paths.

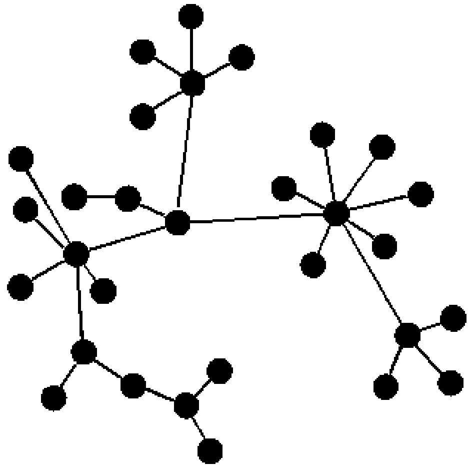
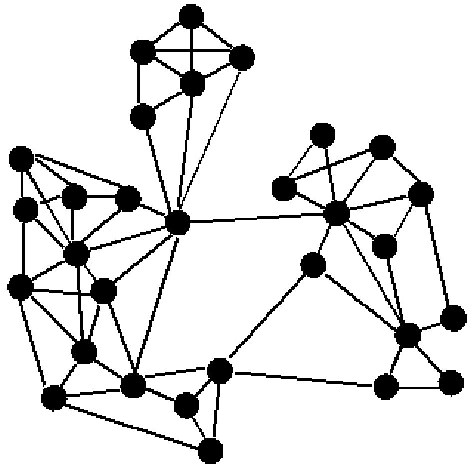
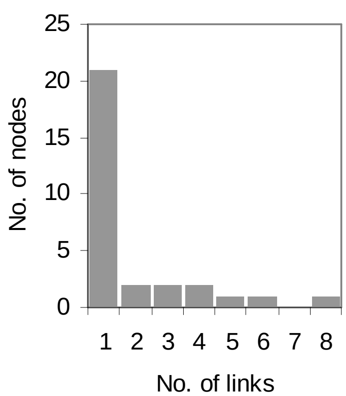
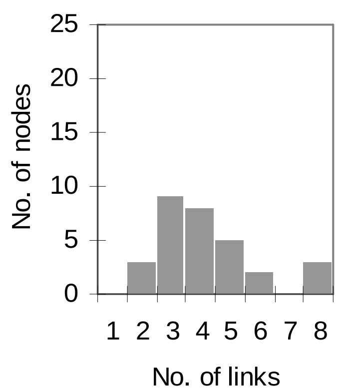
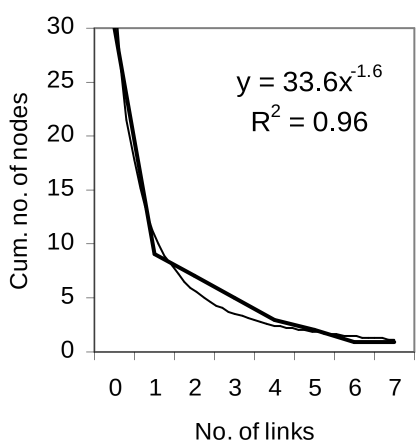
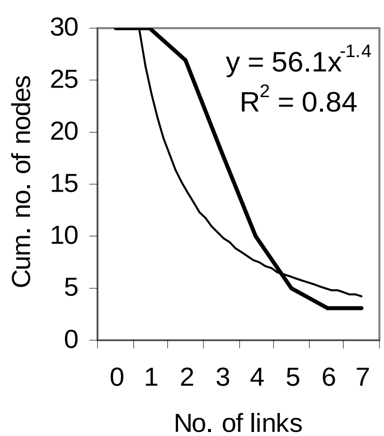
Table 3.3.3 summarises how the four basic network models discussed in Section 2 score against the desirable characteristics just described. It shows that none of these standard network models seems to be a very good model of real personal and social networks.

Table 3.3.3. Summary of characteristics of the four basic network models.

Characteristic	Regular	Random	Small-world	Preferential attachment
Personal networks				
Personal network size limited	✓	✓	✓	X
Variation in size of personal networks, with fat-tail distribution where appropriate	X	X	X	✓
High clustering	✓	X	✓	X
Change over time	X	X	X	Only growth
Social networks				
Low density	✓	✓	✓	✓
Short path lengths	X	✓	✓	Possible
Positive assortativity	X	X	X	X
Communities	X	X	X	✓

In effect, a good model of a social network would resemble the preferential attachment model but with more links to provide more higher clustering, and more links between those who are well-connected, but nevertheless with a cut-off; and specify way of changing over time. To illustrate what this might look like, Fig. 3.3.3 compares the scale-free model of panel (d) in Fig. 3.2.1 with the same model extended to reflect social networks. The problem is how to generate such a network and this is addressed in the next Chapter.

Fig. 3.3.3: Comparison of the preferential attachment model and a social network.

<table>
<tr><td>Preferential attachment</td><td>Social network?</td></tr>
<tr><td></td><td></td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>No. of nodes = 30
Average degree of connectivity = 1.9</td><td>No. of nodes = 30
Average degree of connectivity = 4.2</td></tr>
</table>

Chapter 4: A New Model of Social Networks

The previous Chapter explained why existing network models are not good models of social networks. This Chapter presents a new model, using agent-based modelling, first set out in Hamill & Gilbert (2009). In addition to the four basic models described in the previous Chapter, recently two agent-based models have been proposed:

- Pujol et al (2005) also concluded that the small world and scale free models are based on “unrealistic” sociological assumptions. However, they based their agent-based model on social exchange theory that implies that people weigh the costs and benefits of social relationships. This is highly contentious among sociologists (see e.g. Harper, 2003). A model that does not rely on such strong sociological assumptions is needed.
- Thiriot & Kant (2008) produced a methodology using Bayesian techniques to bring together diverse data sets to create an agent-based model of a social network with “high clustering rate, low density and a low average path length”.

The approach taken here is different: this agent-based social network model is based on a minimum number of sociologically plausible assumptions and minimal data.

As discussed in Chapter 3, homophily is an important determinant of the structure of society. To reflect this, Watts et al (2002) produced a model in which “the probability of acquaintance between individuals” “decreases with decreasing similarity of the groups to which they belong”. In their model, by tuning a single parameter, they could create a “completely homophilous world of isolated cliques” or at the other extreme “a uniform random graph in which the notion of individual similarity or dissimilarity has become irrelevant”. Newman et al (2006, p.292) suggested that this model is “possibly moderately realistic…based on a hierarchical division into groups”. The model presented here draws on these ideas. Section 1 describes the basic structure of the model, which is extended in Section 2. Dynamics are added in Section 3 and Section 4 concludes.

4.1 Basic Structure of the Model

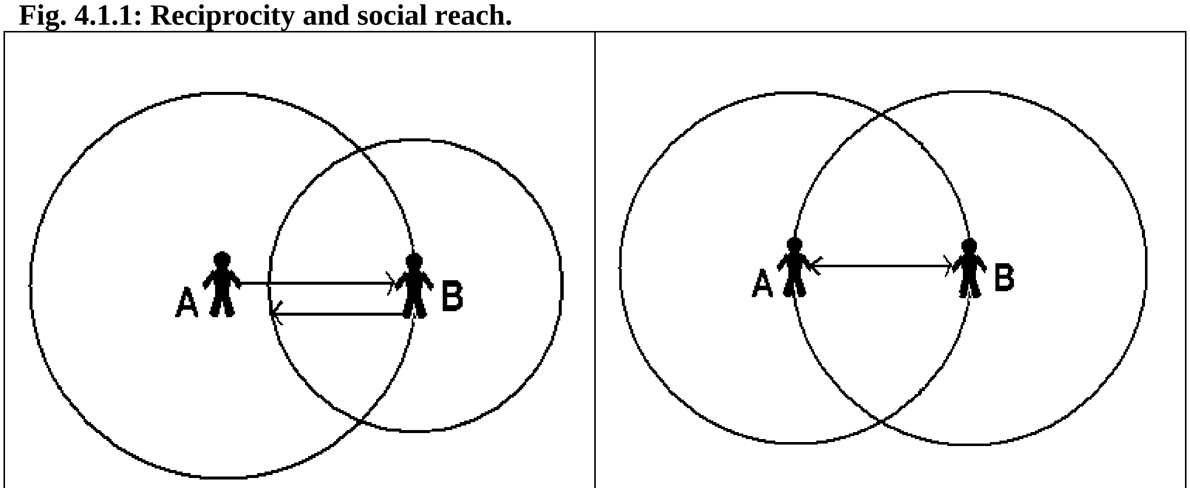
The model is based on the ideas of social space and social distance, which can be traced back to Park (1924?) and was developed by Heider (1958, p.191) among others. McFarland & Brown (1973, pp.226-7) suggested that social distance could be used in two distinct ways: to measure interaction, where those who are short distances apart are likely to interact (which they attributed to Bogardus), and to measure similarity, where short distances imply similar characteristics (which they attributed to Sorokin (1927/1959, pp.3-10). Faust (1988) showed how different criteria could be used to draw different social maps of the same group of people. Wasserman & Faust (1994, pp.385-7) used multidimensional scaling to map "a set of entities in a low dimensional space so that those entities that are more similar to each other are closer in the space". More recently, Hoff et al (2002) used the concept of social distance on three 'classic' sets of network data to obtain better explanatory models than could be obtained using alternative approaches. Finally, Edmonds (2006) argued that it is important to bring together physical and social spaces and argued that the only way to do that is by using agent-based models. Models similar to that proposed below have been reported in the physics literature, e.g. Barthélemy (2003) and Hermann et al (2003).

The setting for the model is what could be called a social map. While a geographical map shows how places are distributed and linked, the social map does the same for people. In this model, the closer any pair of agents, the shorter the social distance between them. If it were considered that geographical distance alone determined social relationships, then this social map could become a geographical map with distance measured in miles or travel time. However, Wellman (1996) argued that "most intimate and other active ties are not with neighbours". And the data produced by Coulthard et al (2002) showed that just over half the people in Britain knew few or none of their neighbours in 2000.

The model is based on the concept of social circles, an idea dating back to at least Simmel (1902). The term "circle" was then used as metaphor. Yet a circle has a very useful property in this context: the formal definition of a circle is "the set of points equidistant from a given point", the centre (Weisstein, 1998, p.246). The circumference of a circle will contain all those points within a distance set by the radius – which will henceforth be called the 'social reach' – and creates a cut-off, limiting the size of personal networks. For a given distribution of agents across the map, a small reach can create a disconnected, gesellschaft-type society; a large social reach, a connected, gemeinschaft-type society. Alternatively, if the social reach is very small, it can be said to replicate a network of close family and friends: if larger, it becomes a model for larger networks including acquaintances.

Agents are permitted to link only with agents who can reciprocate i.e. agents must be within each other's social reach to link. If this were not so, then if A were to have a bigger social reach than B, then B could be in A's circle but not vice-versa; this would imply that A 'knows' B but B does not 'know' A, as illustrated in Fig. 4.1.1(a). Although there may be all sorts of asymmetries in the relationship between A and B and in their communication pattern, they must in some sense both 'know' each other. This definition thus excludes, for example, 'knowing' a celebrity seen on TV where there is no reciprocal contact. This assumption is discussed further in the last Section. The simplest way to achieve reciprocity is for all agents to have the same reach, as shown in Fig. 4.1.1(b), but this assumption is not essential, and will be relaxed later. However, I start by exploring the properties of the simplest model, in which all agents have the same social reach.

Fig. 4.1.1: Reciprocity and social reach.



(a) No reciprocity: different social reaches: A knows B but B does not know A

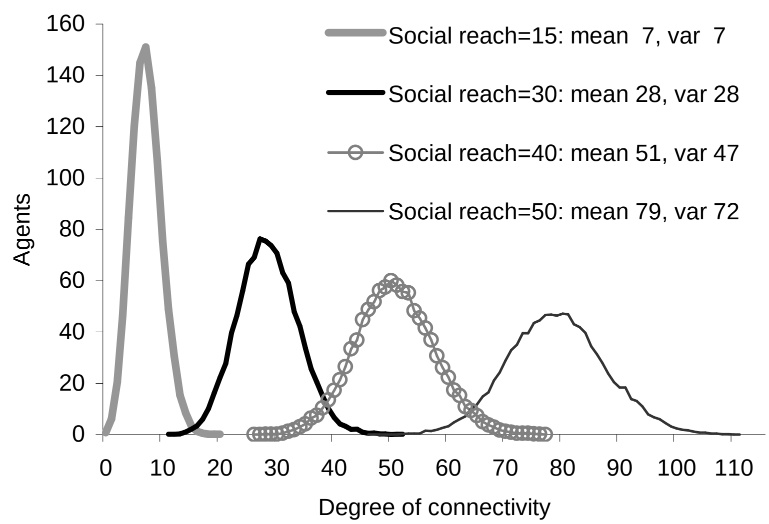
(b) Reciprocity with the same social reach.

Ceteris paribus, the size of personal networks will vary with social reach: the larger the reach, the larger the size of the personal network. To represent personal networks larger than ‘intimates’, a large population of agents is required. The simulations presented in this thesis use a population of 1,000 agents, meaning that there are almost half a million possible undirected links (1,000 × 999 / 2). These agents are randomly distributed across an unbounded grid of just under 100,000 cells, thus producing a population density of about 1 percent.

Degree and density

Hermann et al (2003) studied a similar model based on “a continuous manifold” (rather than the discrete torus used here) and suggested that in such a spatial model, as the number of nodes is increased and the social reach reduced, the connectivity distribution tends towards a Poisson distribution. Fig. 4.1.2 shows how the connectivity of the agents changes as the social reach is increased: the distribution is flattened. For a social reach of up to about 30, the connectivity of nodes follows a Poisson distribution – the mean is the same as the variance – suggesting a random network; but for larger social reaches, the mean tends to exceed the variance. (To explore reaches larger than 50, more agents are needed.)

Fig. 4.1.2: Degree of connectivity by social reach.

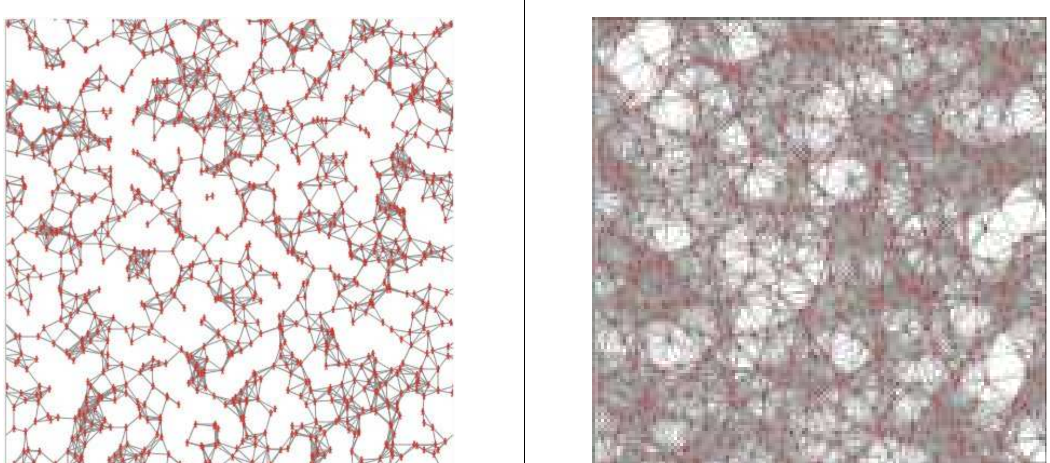


Although the personal networks of all the agents are defined by the same social reach, the numbers in each personal network will vary due to the randomness in the distribution of agents across the social map.

- Setting the social reach at 15 produces an average personal network (or degree of connectivity) of 7. With this small social reach, many agents have few, or even, no links but some may have as many as 20 links. In total there are some 3½ thousand undirected links giving a whole network density of 0.7 percent. This is illustrated in the left hand panel of Fig. 4.1.3: the (red) dots indicate agents and the (grey) lines, the links between them.
- Setting the social reach at 30 produces an average personal network of 28, ranging in size from 11 to 52. Now there are some 14 thousand undirected links giving a whole network density of almost 3 percent. This is illustrated in the right-hand panel of Fig. 4.1.3.

In both cases, communities (i.e. groups of agents that are well connected within themselves but loosely connected to other groups) can be seen.

Fig. 4.1 3: Samples of networks with different social reaches.
(Red nodes, grey links.)



Social reach = 15	Social reach = 30
Average personal network size = 7.2 Total no. of undirected links = 3,600 Whole network density = 0.7%	Average personal network size = 28.4 Total no. of undirected links = 14,200 Whole network density = 2.8%

Clustering

In Chapter 3, a node's clustering coefficient was defined as the extent to which the nodes connected to it are in turn linked to each other (Scott, 1991, p.74). In this model, in which all agents have the same social reach, where agents are located very close to each other, their circles will largely overlap and they will know most of the same agents. At the other extreme, when an agent is located on the circumference of another's circle, the overlap will cover 39 percent of the area of each circle. (This is illustrated in the top right hand panel of Box 4.1.1, with the mathematics in top left hand panel.) Thus if agents are uniformly distributed over the space, then the minimum clustering coefficient will be 0.39.

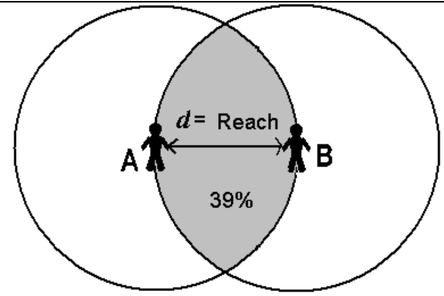
Given the geometry of circles, and the assumed uniform distribution of agents, then half the agents in a personal network will be within 0.7 of the reach (as shown in the middle panel of Box 4.1.1). In these circumstances, the agent will have a clustering coefficient of 0.56 or more with half of the agents in its network; and a coefficient of between 0.39 and 0.56 with the remainder (as shown in the bottom panel of Box 4.1.1). This is only a theoretical result as it will only be observed if the agents are evenly distributed. In practice, agents will not be evenly distributed, as illustrated in Fig. 4.1.3.

Box 4.1.1: Mathematics of circles.

The area overlapping is given by the formula

$$2\arccos\left(\frac{1}{2}\right)d - \left(\frac{1}{2}\right)d\sqrt{4-d^2}$$

where d is the distance between the two centres of the circles (Weisstein, 1998, p.250).

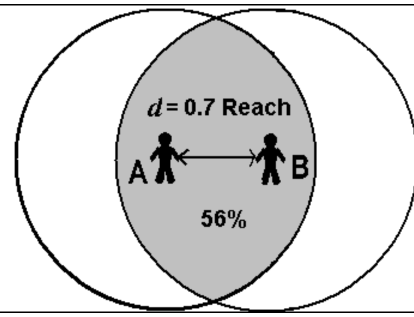


When d = the unit radius, this reduces to

$$2\arccos\left(\frac{1}{2}\right) - \left(\frac{1}{2}\right)\sqrt{3}$$

= 2.09 – 0.87 = 1.23

The area of the unit circle is π, (as $r^2 = 1$) so the proportion overlapping is 1.23/3.14 = 0.39.

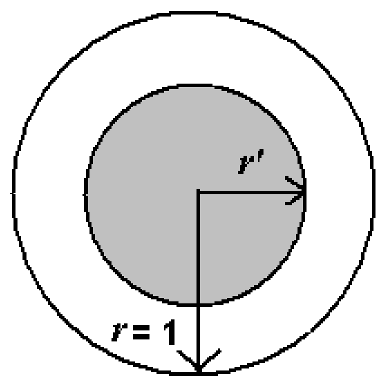


Area of a circle = πr^2
Percentage of the area of the large circle covered by inner (grey) circle of radius r' =

$$\frac{\Pi r'^2}{\Pi r^2} = \frac{r'^2}{r^2}$$

If $r = 1$, then $r^2 = 1$, and so the percentage of the area covered by inner (grey) circle of radius r' =
r'^2.

So if r' = 0.7 then 49% of the area of the larger circle will be covered by the smaller (grey) circle.



Summary

The table shows how the clustering coefficient varies if agents are distributed uniformly.

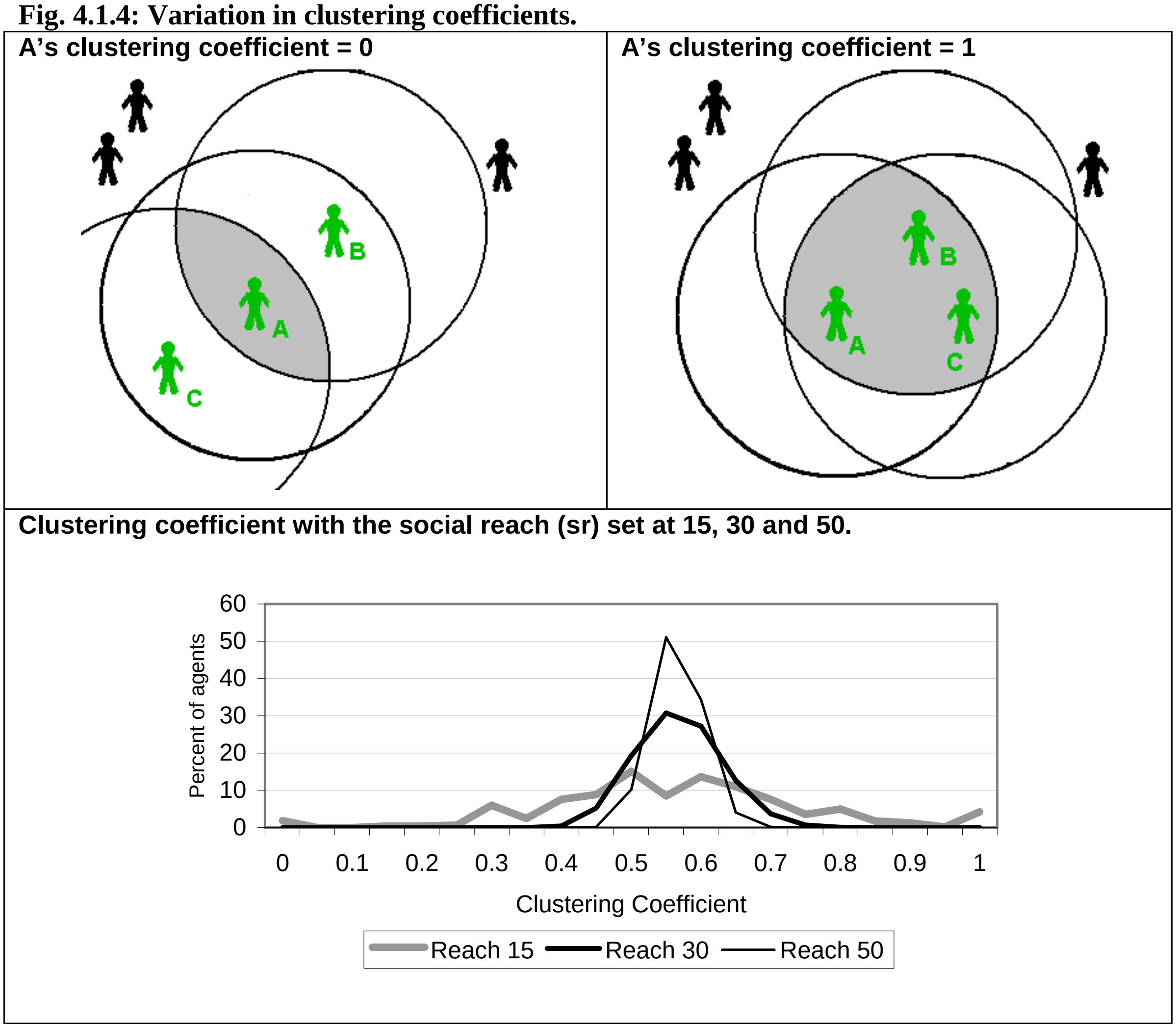
If the distance between agent A and agent B is equal to the radius (or reach), then 39% of the agents in A's circle will also be in B's circle. By definition, all agents A knows are within the radius. This set of results is shown in the bottom row of the table.

If the distance between A and B is 0.7 of the radius (or reach) then 56% of the agents in A's circle will also be in agent B's circle. Half the agents in A's personal network will be within 0.7 of the radius (reach). This is shown in the shaded row in the table.

d **relative to radius**	**Percent area overlapping**	**Cumulative percent of agents within** ***d*** *****
0	100	0
0.1	94	1
0.2	87	4
0.3	81	9
0.4	75	16
0.5	69	25
0.6	62	36
0.7	56	49
0.8	50	64
0.9	45	81
1	39	100

In particular, if the social reach is set very low, and thus the personal network size is small, then none of those in an agent's personal network may know each other, giving a clustering of zero; alternatively, all the agents may be close and know each other producing a clustering coefficient of one. Examples of these two extreme cases are illustrated in the top panel of Fig. 4.1.4. In both examples, agent A has a personal network of two, B and C: but in the left hand case, B and C do not know each other while in the right had case, they do. The lower panel of Fig. 4.1.4 shows the results of simulations to calculate agents' clustering coefficients. (The calculation method is explained in Box 4.1.2.) The simulations confirm that the clustering coefficient will vary more for smaller social reaches than larger ones; and as the social reach increases, the minimum of the clustering coefficient will tend to 0.39 with an average of about 0.56.

Fig. 4.1.4: Variation in clustering coefficients.

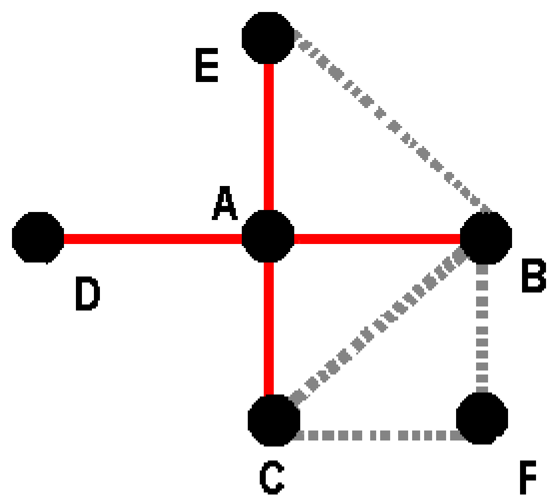


Box 4.1.2: Calculating the cluster coefficient: example and pseudo-code.

There are 4 in A's personal network indicated by solid (red) lines.
Thus there are potentially (4 x 3) / 2 = 6 undirected links among A's network (excluding the links to A).

Of these 6 potential links, 2 exist:
B to C, and B to E – as indicated by broken (grey) lines and in the matrix below. Thus A's clustering coefficient = 2 / 6 = 0.33.

For the other nodes, the clustering coefficient is
B = 3 / 6 = 0.5
C = 2 / 3 = 0.67
D = 0
E = 1 / 1 = 1
F = 1 / 1 = 1



The program works by taking each pair of links in turn and calculating the extent to which the agents at each end are linked to the same other agents.

Pseudo-code	**Example** Link A to B
Total links = sum of the number of links to the agents at each end of the link	A = 4 & B = 4 Total links = 8
List the agents' links	A's links: B, C, D, E B's links: A, C, E, F
Eliminate duplicates	A, B, C, D, E, F
Net links = number left	6
Calculate the overlap = total links *less* the net links	8 – 6 = 2
Calculate the overlap ratio for each end * = (overlap / (size of personal network – 1)) ("-1" because the ends don't count)	For A: 2 / (4 – 1) = 0.67 For B: 2 / (4 – 1) = 0.67
Repeat for each link	See below
Calculate the clustering coefficient for the agent by taking the average of the coefficients for each link.	So A's clustering coefficient = (0.67 + 0.33 + 0 + 0.33) / 4 1.33 / 4 = 0.33

Links from A to	Personal network	No. of links A to agent		Overlap	Overlap ration
		Total	Net		
B	4: A, C, E, F	8	6	2	2 / (4 – 1) = 0.67
C	3: A, B, F	7	6	1	1 / (4 – 1) = 0.33
D	1: A	1	1	0	0
E	2: A, B	2	1	1	1 / (4 – 1) = 0.33
A's clustering coefficient (average of above)					0.33

* In this example it happens to be the same for each end of the link, but this may not be the case.

Path length

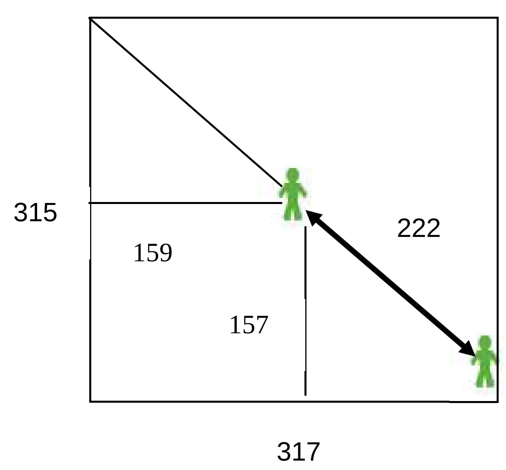
The minimum number of links from one agent to another, the path length, is determined by the size of the 'world', the social reach and the distribution of agents. Ignoring the distribution of agents, using geometry it is possible to calculate the theoretical path length given the social reach and the size of the world. (Details in Box 4.1.3.) According to this calculation – which is referred to as the geometrical maximum path length – if the social reach is set at 30, then the maximum number of steps between any pair of agents will be 7.4 given the world size of about 100,000 cells. But this calculation is based on the maximum distance and most agents will therefore be closer, making the average path length shorter. Against this, no account has been taken of how agents are distributed across the space: optimal paths may not be attainable and so the true maximum will probably be higher.

Box 4.1.3: Calculating the theoretical maximum path length using geometry.

Dimensions of grid: 315 x 317 (99,855 cells)
An agent at the centre of this grid will be at least 159 units from the edge (317/2).

But the diagonal provides the furthest distance and by Pythagoras's theorem, this diagonal will be 222 units.

The number of steps needed to cover this distance will depend on the social reach: the smaller reach, the more steps needed.
So if the social reach were set at 30, then there would be a theoretical minimum of 222/30 = 7.4 between the two most distant agents: if the reach were 15, it would take 14.8 steps.



The answer is, of course, to calculate the path lengths. However, calculating path lengths requires a fully-linked network, and in this case, this means that it cannot always be calculated if the social reach is small because, as shown in Fig. 4.1.5, even a reach of 15 can result in isolates or isolated groups. If the reach is 30, then the network is fully connected. The path lengths were calculated using the "Floyd Warshall algorithm for All Pairs Shortest Paths" from the Small-World program in the NetLogo Library (Wilensky, 2009c). With 1,000 agents with a social reach of 30, this took about 24 hours for a single run. (This is because NetLogo is slow and with a social reach of 30, each agent has on average a personal network of 28 agents (as shown in Fig. 4.1.2) and so there are some 28,000 links to be explored.) However, using a model a quarter of the size – with 250 agents and 7,000 links –it was practical to calculate the path lengths even with a social reach of 30. Thus smaller worlds have been used to help to confirm the path lengths suggested by a few runs using the full world of 1,000 agents.

Applying the algorithm to smaller versions of the model produced average path lengths that were less than the geometrical maximum (as calculated in Box 4.1.3), while the actual maxima were larger, as was expected. The results (shown in the first two columns of Table 4 1.1) suggest that the average path length for 1,000 agents with a reach of 30 in a world of 100,000 cells might be about three quarters of the geometrical maximum i.e. 5 to 6, with a maximum about a third larger i.e. 9 to 10. In addition, 3 runs were done with 1,000 agents and all 3 produced identical results: an average path length of 5.1 and a maximum of 9 (last column of Table 4.1.1) in line with expectations.

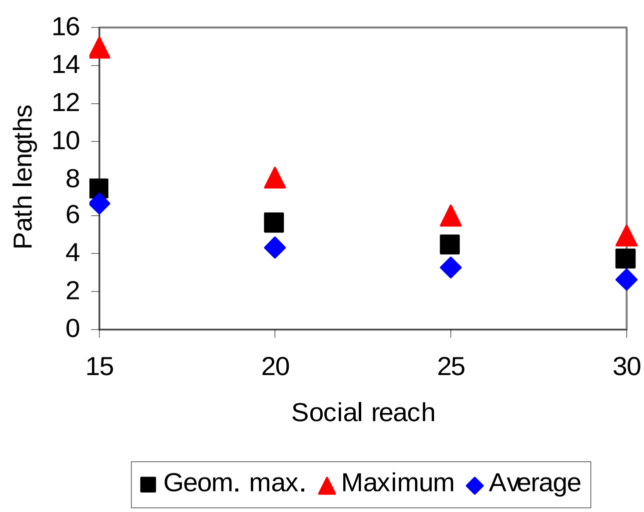
Table 4.1.1: Path-lengths with social reach of 30 with various world sizes.

Model size	**One-tenth size**	**One quarter size**	**Full size**
No. of agents	100	250	1,000
Size of world	9,999	24,963	315 x 317 = 99,855
Population density (%)	1%	1%	1%
Geometrical maximum path-length (See Box. 4.1.3)	2.4	3.7	7.3
Measured path-lengths: - average (*sd*) - maximum (*sd*)	 1.8 (*0.0003*) 3 (*0.0000*)	 2.7 (*0.01*) 5 (*0.00*)	 5.1* 9*

* Based on 3 runs due to excessive run times: results the same for each run (to 1 decimal place).

For practical reasons, a world of 250 agents was used to explore further the relationship between social reach and path lengths. The results are shown in Fig. 4.1.5. The actual maximum path length is larger the smaller the social reach: 15 for a reach of 15, 5 for a reach of 30. As the social reach was increased, the standard deviations around these figures fell i.e. the average and maximum path lengths were less subject to stochastic variation, which would be expected intuitively. An average path length of about 6 can be produced in this smaller world using a social reach of 15. Thus by choosing appropriate values of social reach and world size, this model can be used to produce social worlds consistent with Milgram's six degrees of separation discussed in Chapter 3.

Fig. 4.1.5: Path lengths for the quarter-size one circle model with social reaches of 15 to 30. (1)(2)

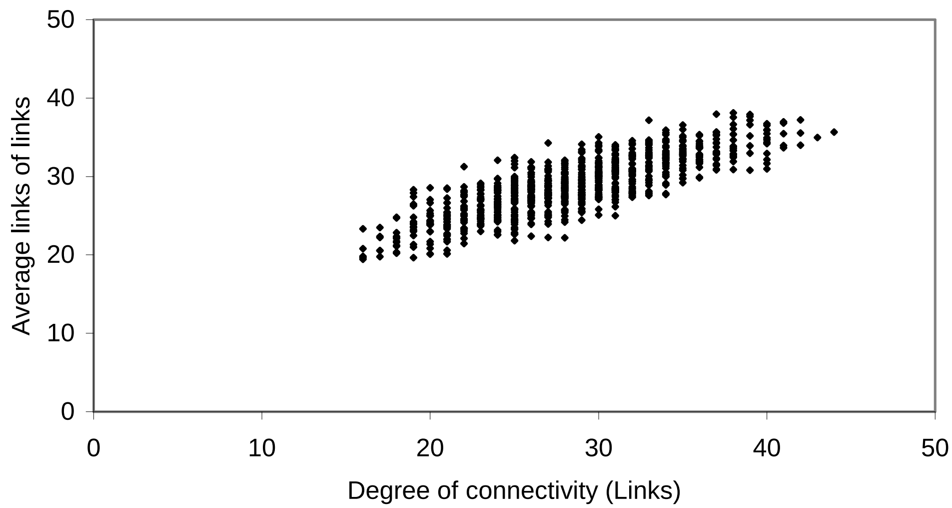


(1) 250 agents in a world 156 x 158 = 24,648 i.e. whole network density = 1%
(2) Social reach of 15: the path lengths were only calculated for those networks which were fully connected.

Assortativity of degree

Intuition suggests that this model should produce networks with positive assortativity by degree of connectivity because agents in densely populated regions will tend to have many links, as will those to whom they are linked (as Hermann et al, 2003, suggested). This proves to be the case. The relationship between an agent's degree of connectivity and the average for those to which it is linked is positively correlated as indicated by the Pearson correlation coefficients (following Barthélemy, 2003). For example, for a social reach of 30, the correlation coefficient averages 0.83 (sd 0.03). (Fig. 4.1.6 shows a typical example.) For the lower reach of 15, it is 0.78 (sd 0.03) and for the higher reach of 50, 0.84 (sd 0.05).

Fig. 4.1.6: Assortativity of degree of connectivity: typical example of correlation between degrees of connectivity: social reach of 30.



4.2 Extending the Model

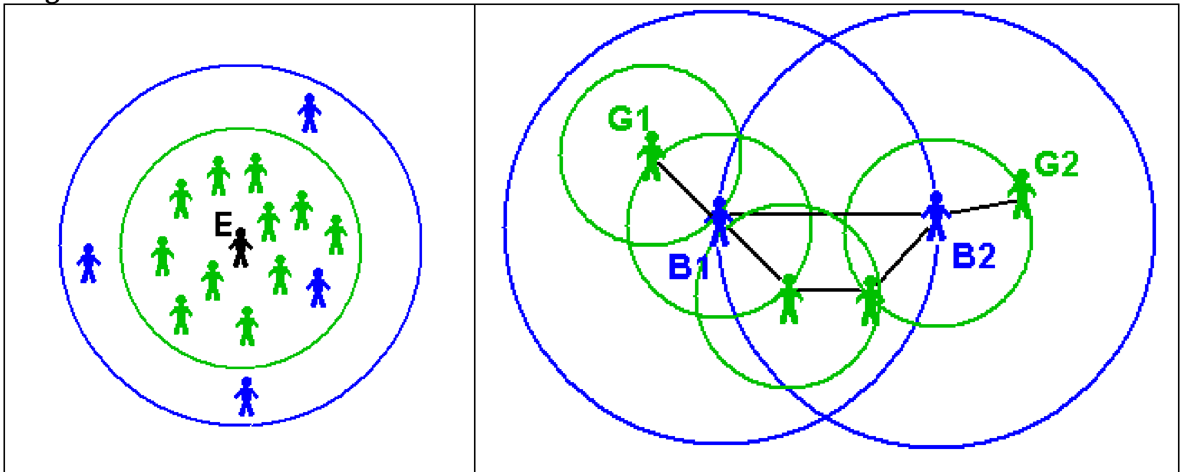
Two reaches

The simple single-reach model is inflexible, the only parameters being population density and the size of the social reach, and while positively assortative it does not produce a fat-tailed distribution of connectivity. Also with larger social reaches all agents will have a clustering coefficient of at least 39 percent. Yet Wellman's work (Scott, 1991, pp.80-2) suggested that the clustering coefficient averaged 33 percent among close associates, often kin, with a fifth having a density exceeding 50 percent.

These issues can be addressed by splitting the population in two and giving one group – call them Blues – a larger social reach than the other – call them Greens – but only permitting links between those who can reciprocate. Thus Green agents link only to other agents – Greens and Blues – within their small reach. But Blues not only link to the Greens within their smaller reach but also to Blues within their larger reach (see left panel of Fig. 4.2.1).

There are therefore two more parameters to adjust: the percentage of Blues (with the larger social reach) and the size of that reach. This has the effect of reducing the clustering coefficient for the Blues; for example, a Blue might share no Greens with a neighbouring Blue. It also reduces path lengths for the Greens because a Blue in their personal network may provide a short cut to agents beyond their reach. In this way, a hierarchy is created. These features are illustrated in the right hand panel of Fig. 4.2.1.

Fig. 4.2.1: Two-reach model.



If E is a Green, then E links with everyone in the smaller (green) circle. If E is a Blue, then E also links to the three Blues within the larger (blue) circle	A link between Blues B1 and B2 creates a short-cut between them and between Greens G1 and G2. For Blues, clustering is reduced as they will know many greens who do not know one another.

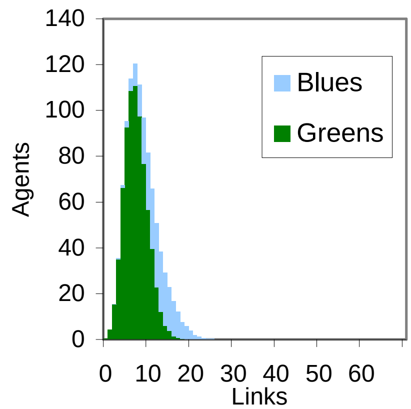
The two-reach model in effect adds together two Poisson distributions and this can produce a distribution with larger variance and a fatter tail. Of course, if the percentage of Blues is small or if there is little difference between the two social reaches, the results from the two-reach model will tend towards that of the one-reach model. Fig. 4.2.2 shows results for a pair of two-reach models with 25 percent Blues. In the first case (illustrated in the left column of Fig. 4.2.2) the well-connected Blues have a social reach of 30 while that of the Greens is only 15; in the second case (illustrated in the right column), the Greens have a social reach of 30 while that of the Blues is 50.

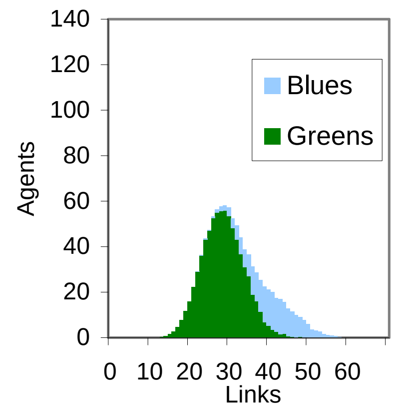
Four results emerge:

- The better-connected Blues add a fat tail to the distribution of degrees of connectivity: in both cases, the overall variance is significantly greater than the mean, and the distributions spread more widely than a Poisson. In both cases about half the links involve at least one Blue even though only a quarter of the agents are Blues.
- The size of personal networks of the better connected Blues is constrained by the relatively few Blues: it is much lower than would be expected if all agents had their larger reach. For example, in the first case, although the Blues have a reach of 30 their personal networks average only 12, far fewer than the average of 28 that is found when all agents have a reach of 30 (as shown in Fig. 4.1.2).
- In accordance with expectations, on average the Blues have a lower clustering coefficient than the Greens. Furthermore, while the distribution of the clustering coefficient of the Greens is negatively skewed, that of the Blues is more symmetrically distributed.
- Overall the assortativity is slightly weaker than in the one-reach model because although the Blues link to other well-connected Blues, more than half of their links are to the less well-connected Greens. (Typical examples are illustrated in the bottom row of Fig. 4.2.2.)

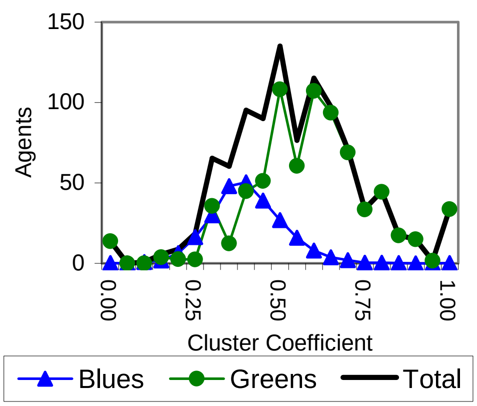
Fig. 4.2 2: Examples of two-reach models: Blues 25 percent.
(PN = personal network)

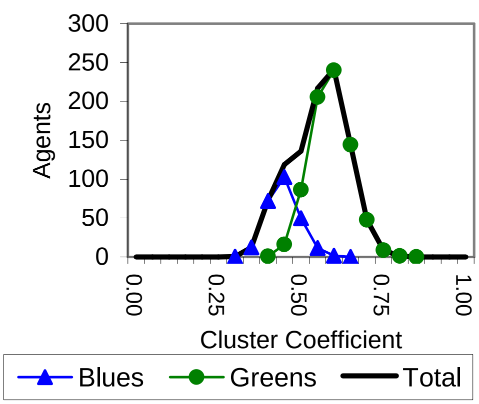
Greens' reach = 15: Blues' reach = 30	Greens' reach = 30: Blues' reach = 50



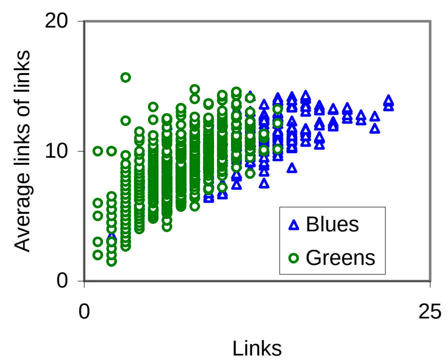


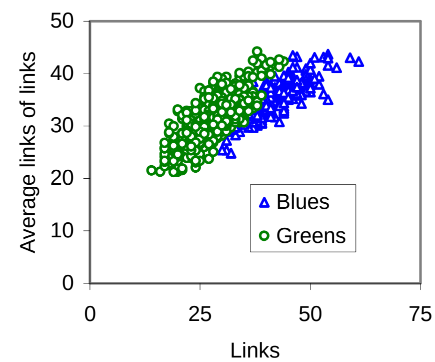
Average PN	Blues 12	Greens 7	All 8	Average PN	Blues 41	Greens 28	All 32
% links	B-B 21	B-G 32	G-G 47	% links	B-B 16	B-G 34	G-G 51





Cluster coeff.	Blues 0.42	Greens 0.61	All 0.56	Cluster coeff.	Blues 0.47	Greens 0.61	All 0.57



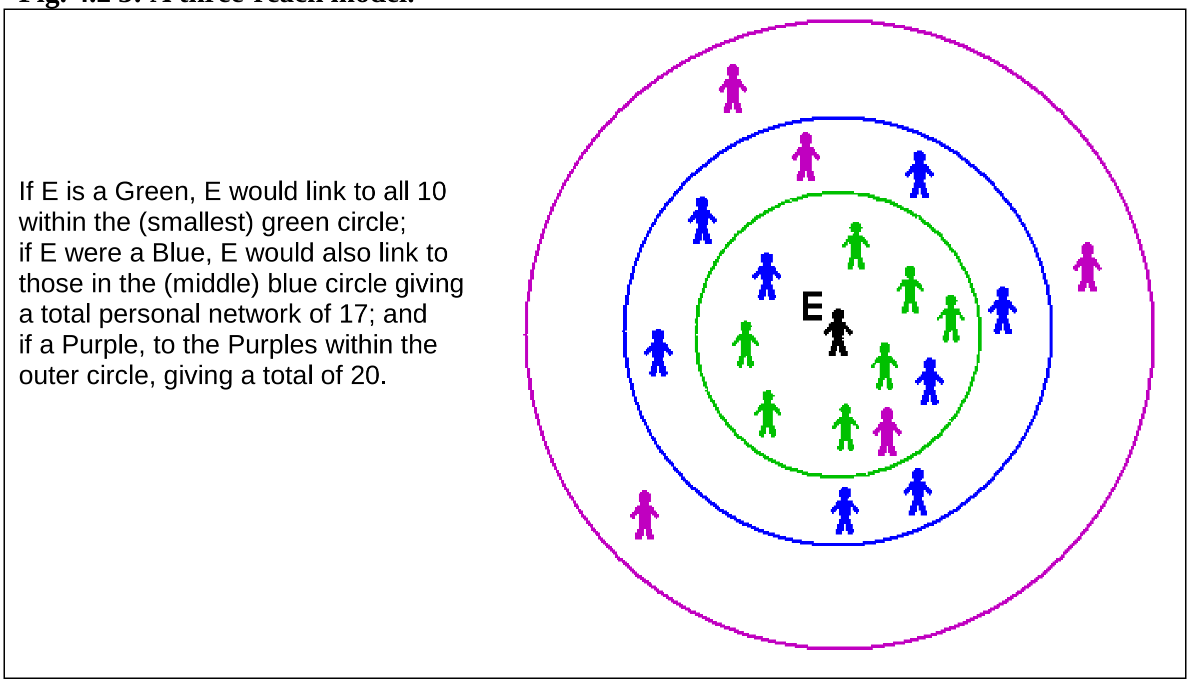


Assortativity (r)	Blues 0.69	Greens 0.69	All 0.71	Assortativity (r)	Blues 0.78	Greens 0.79	All 0.75

Three reaches

Adding a third reach increases the flexibility of the model still further. Fig. 4.2.3 shows how this would work by adding Purple agents to the Greens and Blues. But, as before, an agent can only link to those capable of reciprocating.

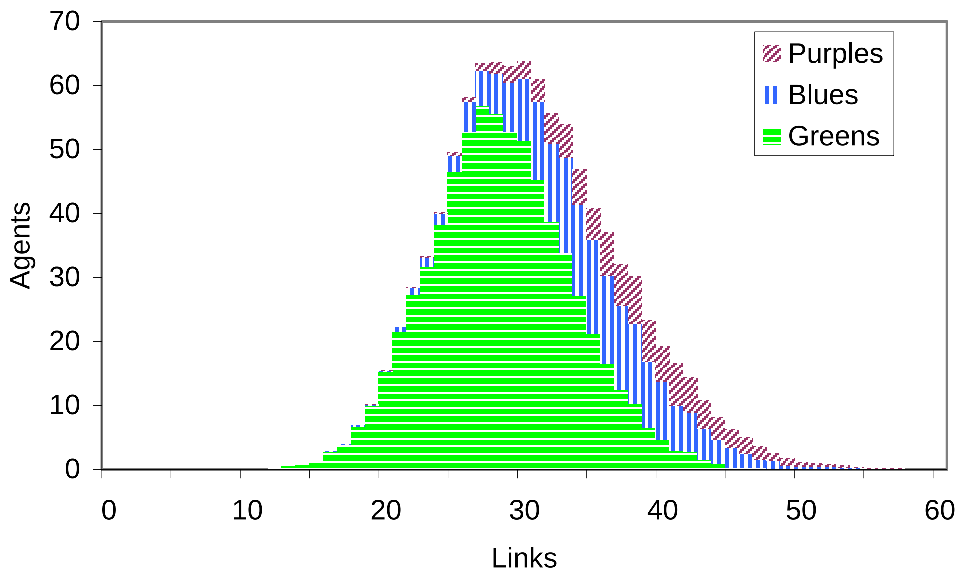
Fig. 4.2 3: A three-reach model.



The flexibility of the three-reach model is illustrated by an example that demonstrates how two very different types of networks can be created by choosing different parameters. In both cases, the three social reaches are set at 30, 40 and 50 but in the 'elitist' case agents are distributed in the proportions 70/20/10 percent while in the 'democratic' case they are split evenly at 34/33/33 percent. The results are shown in Fig. 4.2.4. The whole network density is 3 percent in the elitist case and 4 percent in the democratic case. In both cases the overall distribution of degrees of connectivity is wider than a Poisson distribution, notably so for the democratic case. But for each type of agent – Green, Blue or Purple – the distribution is approximately Poisson as indicated by the fact that the means are roughly the same as the variance. In other words, the Poisson distributions are added together to produce distributions ranging from a Poisson with a fat tail to one that is starting to resemble a uniform distribution.

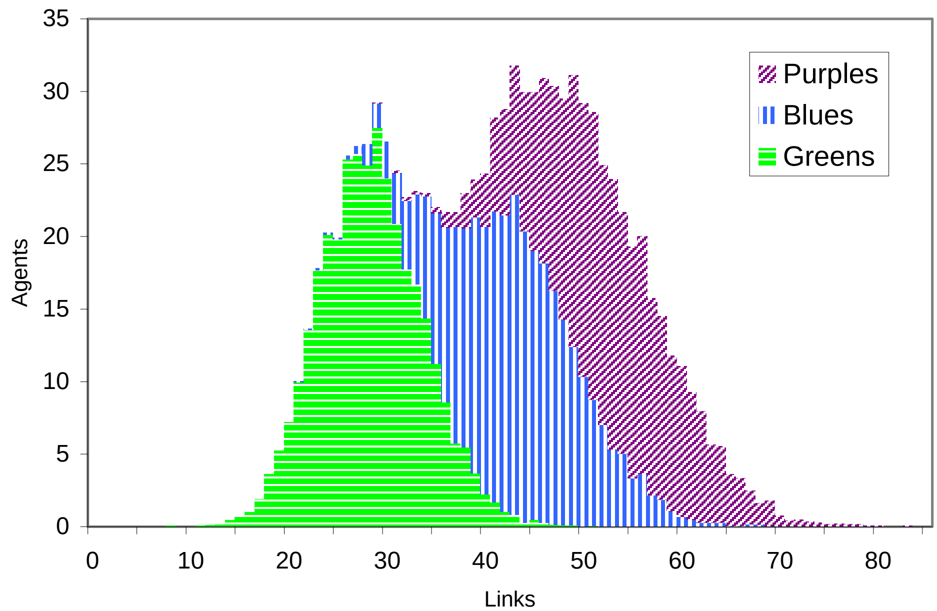
Fig. 4.2.4: Two examples of degrees of connectivity in a three-reach model.

Elite: 70% Greens, 20% Blues, 10% Purples



	Greens	Blues	Purples	All
Mean	28	35	38	31
Variance	26	32	34	41

Democratic: 34% Greens, 33% Blues, 33% Purples



	Greens	Blues	Purples	All
Mean	28	43	52	41
Variance	28	41	50	138

Whether or not this flexibility is required and whether the additional complication is justified compared to the two-reach model will depend on the questions to be addressed by the modelling. For instance, the three-reach model would be appropriate if there were three distinct groups involved in the process being modelled, e.g. those who are globally connected, nationally connected or only regionally connected.

N-reaches

Each agent can have a different social reach provided that any pair of agents link only if both their social reaches permit. For example, if agent A has a social reach of 25 and agent B has a reach of 30, then providing the distance between A and B is no more than 25, they can link. Rather than choosing the percentage of agents with given social reaches as in the previous examples, it now becomes necessary to choose the distribution of social reaches and the parameters of those distributions. There is not an obvious choice.

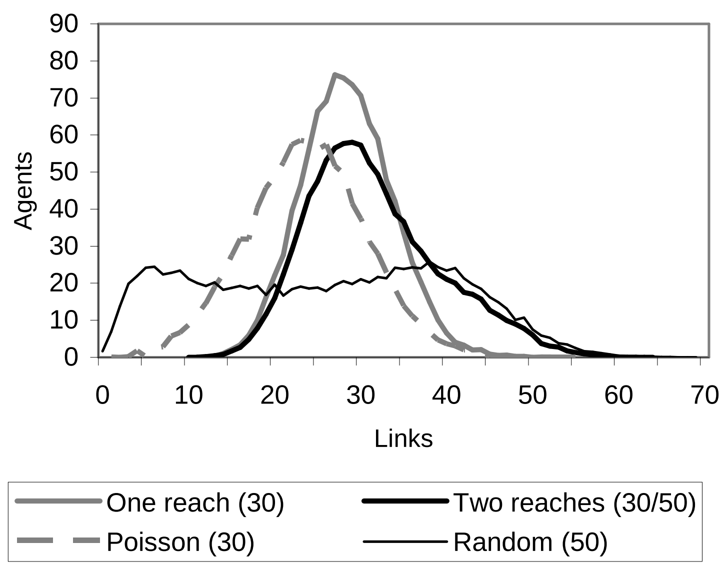
Two types of distributions have been examined: uniform and Poisson. For the uniform distribution, minimum and maximum reaches were chosen and for the Poisson, just the mean (which then equals the variance). To illustrate this approach, Fig. 4.2.5 compares the results from using Poisson and uniform distributions with those obtained by using one or two reaches to produce an average personal network of around 30. In this case, compared with using fixed reaches, using variable reaches reduces the assortativity and increases the range of size of both personal networks and the clustering coefficients, especially if a uniform distribution is used; and neither the Poisson nor the uniform distributions of reach produce fat tails, as shown in the bottom panel of Fig.4.2.5.

This approach is computationally more complex and increases the length of time taken for each run. Whether these costs outweigh the benefits is a matter of judgment and depends on the question being addressed.

Fig. 4.2.5: Comparison of various ways of producing an average personal network of around 30.

Type of distribution (Parameters)	One circle (30)	Two circles (75%: 30, 25%: 50)	Poisson (mean 30)	Random (range 10-59)
Personal Network Size				
Minimum	14	14	4	0
Average	28	32	23	26
Maximum	44	58	43	59
Cluster Coeff				
Minimum	0.41	0.35	0.32 (1)	0
Average	0.59	0.56	0.59	0.62
Maximum	0.79	0.81	1	1
Density				
Total no. of links (thous)	14.2	15.8	11.7	13.0
Density: % possible links	2.8	3.2	2.3	2.6
Assortativity (r)	0.83	0.75	0.65	0.66

(1) Average: some runs will produce 0.



4.3 Dynamics

It was noted in Section 3.3 that personal networks were constantly changing. Putting aside the issue of changes due to mortality, which will be discussed later in the case studies, personal networks change because people drift apart, either by physically moving away or by changing behaviour. It is therefore necessary to introduce a change parameter that allows a proportion of agents to move in the social space. If this change is random, it will change the size and composition of individual agents' networks, but it will not change the overall structure of the society. To achieve this, an extra parameter, called the 'socialshift', was added to the model. The socialshift is the percentage of agents who move each time step. To assess the impact of the smallest possible changes, it was assumed that the distance moved was just one unit.

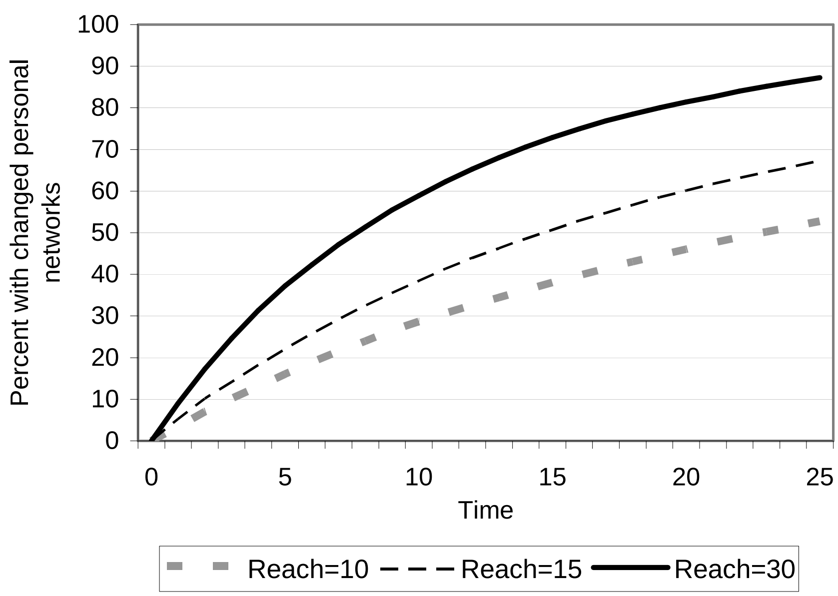
Because the agents are selected to move randomly, the mathematics show that, for example, if 50 percent of agents moved in each time period, then only 25 percent would move in both the first and second periods, and only 12½ percent would also move in the third period. If only 5 percent of agents – one in 20 – moved every period the then probability that an agent who moved in period 1 would also move in period 2 is one in 400. Simulation shows that with 'socialshifting' set at 5% then on average over 10 periods, each agent that moves does so only about 1¼ times.

When an agent moves, its personal network may change in size, composition or both. Furthermore, moves may affect others who do not themselves move. Indeed, the larger the social reach, the more agents will potentially be affected by another agent's move. The effect of this socialshifting on agents' personal networks was examined, according to whether or not they moved and whether or not the size or composition of their social circles changed. If neither the number nor identity of agents in their personal network changed, they were counted as unaffected. Fig. 4.3.1 shows the proportion of agents whose personal networks change when socialshifting is set at 5 percent:

- if the social reach is set at 10, giving an average personal network size of about 3, then after 10 time steps, the personal networks of about a third of agents are changed; after 25 steps, just over half.
- if the social reach is set at 30, giving an average personal network size of about 28, then after 10 time steps, the personal networks of 60 percent of agents are changed; after 25 steps, nearly 90 percent.

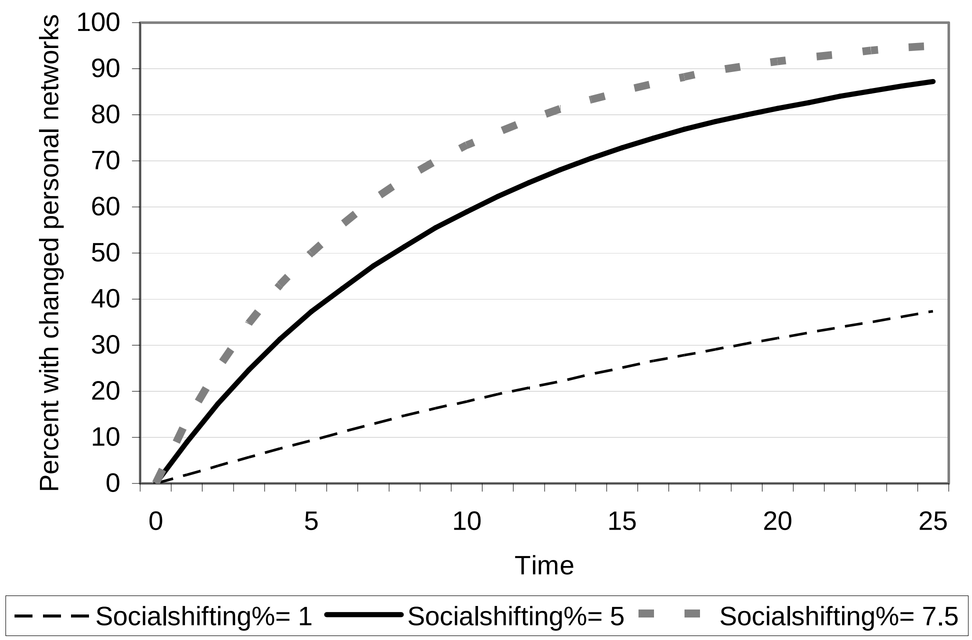
Put another way, if just 1 in 20 shift one step each period, then over 10 periods, between a third of small personal networks and almost two-thirds of larger ones will change. These results are consistent with the findings of longitudinal studies discussed in Chapter 3.

Fig. 4.3.1: Percentage of agents whose personal networks are affected by 5% socialshifting by social reach.



Of course, if a lower rate of socialshifting is assumed, then the proportion of agents affected is less; if higher, more. This is illustrated for a social reach of 30 in Fig. 4.3.2. Even with a socialshifting rate of only 1 percent, just over a third of agents are affected after 25 time steps: if socialshifting is set at 5 or 7½ percent, then around 90 percent are affected. (There is little difference after 25 steps between 5 and 7½ percent because at those levels of shifting, most agents move: 73 percent at 5 percent socialshifting, 86 percent at 7½ percent.)

Fig. 4.3.2: Percentage of agents whose personal networks are affected by different rates of socialshifting given a social reach of 30.



4.4 Discussion and Summary

This Chapter has presented a simple method to create large social networks in agent-based models that represents social networks better than the four standard network models (regular lattice, random, small-world and preferential attachment). To some extent, this new model meets all the criteria set out in Chapter 3 in that it creates personal networks that:

- are limited in the size by using the social reach as a cut-off;
- vary in size between individuals by randomly distributing agents across the social map and varying the size of the social reach; and can have fat-tailed distributions of connectivity when more than one social reach is used with appropriate parameters;
- display high clustering, generated by the overlapping social reaches: the clustering coefficient tends to average around 0.5 but for individual agents can vary from zero to one depending on the parameters chosen;
- can change over time.

It also produces social networks that:

- have low whole network density: the lower the social reach, the lower the whole network density; for example, personal networks averaging around 30 produce social networks with a density of around 3 percent;
- are assortative by degree of connectivity: well-connected agents tend to be connected to other well-connected agents with the assortativity index, measured by the Pearson correlation coefficient, over 0.5;
- have communities;
- can have short path lengths depending on values chosen for social reach, number of agents and world size.

The final criterion was that the model should not rest on strong sociological domain specific assumptions. Like any model, it is a simplification of the real world. There are two key assumptions underlying the model, which I consider to be sociologically acceptable at least for relatively abstract modelling: symmetrical relationships and the use of two dimensional space.

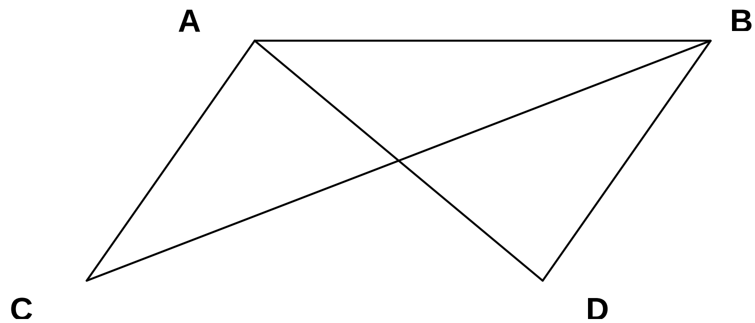
The model assumes that personal networks can be added together to create a social network. This requires that relationships be symmetrical. Reciprocity tends to be the norm in social person-to-person communication: for instance, if you say hello to me, I would be rude not to say hello to you; if I send you a Christmas card, I expect one in return. Formal, macro evidence is more difficult to find but the limited data confirms reciprocity:

- Zipf (1949/1965, p.400) noted that the number telegrams received by a city equalled the number sent.
- more recently, Garlaschelli & Loffredo (2004) examined data from two email networks – one based on address books (Newman et al, 2002) and the other on actual messages sent (Ebel at al, 2002) – and found strong evidence of reciprocity.

Whether this is realistic depends on what aspect of social relationships are being analysed. For example, within a kinship group, the biological relationship must be in a sense reciprocal: if A is a cousin of B, then B is, by definition, a cousin of A or if C is the parent of D then D is the child of C. But this may not hold for other types of social networks. It is well-established that many relationships are asymmetrical in strength (Wellman, 1988, pp.40-41): A loves B but B does not love A. Such asymmetrical social relationships can be modelled using directed links (i.e. distinguishing between links *to* a node and links *from* a node (Wasserman & Faust, 1994, pp.121 & 126)) and weighted links to reflect the 'traffic', somehow defined, that passes along them. This is something to be explored in further work.

The second key assumption is the use of two dimensions for the social map. This imposes limits on the structure of the network by what can be called the parallelogram problem. Consider four agents: A, B, C and D. If A, B and C are linked and A, B and D are also linked, then the distance between C and D is fixed by the laws of geometry as illustrated in Fig. 4.4.1. However, if C and D both know a fifth agent, E, who does not know A and B, it may not be possible to accurately show both links on a two dimensional map although it would be possible using three or more dimensions.

Fig. 4.4.1: The parallelogram problem.



Summary

The model is based on the metaphor of social circles and makes use of the geometrical properties of circles. The radius of the circle has been labelled the social reach. The two-reach model seems to be particularly useful in that, although simple, it provides the essential features of a social network. However, three or more reaches can be used, and even different reaches for each agent, but whether the costs in terms of more complicated programs and longer run-times are justified will depend on the question being addressed.

By allowing agents to move randomly, changes can be made in personal networks while maintaining the overall social structure. The cumulative effect of assuming a small proportion of agents move a small distance can change the size and identity of the personal networks of almost all the agents over a long period of time.

Further work includes increasing the number of agents, measuring path lengths better, distributing agents differently, changing the distributions of connectivity, incorporating strength of ties, and increasing interactivity between agents. However, the model as presented provides a simple structure for modelling large social networks and is particularly suitable for use when little data are available, for example, for historical simulations, or for use in abstract simulations of artificial societies. On the basis of the criteria selected, it is better than the traditional alternatives and therefore it forms the basis for the case studies developed in later chapters.

Chapter 5: The General Model

This thesis is about the relationship between social, communication and transport networks. Chapter 4 set out a new method of modelling social networks. It is now necessary to extend the model to communications and travel. Following the argument made in Chapter 3 that communications networks are generated by people in a much more direct manner than are transport networks, the model focuses on the interaction between social and communication networks, with travel being taken as a possible outcome. The social network model described in Chapter 4 is therefore extended by adding the adoption and use of communication travel technologies and the impact on travel.

This Chapter sets out a general model in the sense that it does not apply to any particular mode of communication, mode of travel or time period. For each case study, only certain elements will be used, applying the principle of Occam's Razor: *entia non sunt multiplicanda praeter necessitatem* or "entities are not to be multiplied beyond necessity" (*Oxford Dictionary of Philosophy*, 1996).

To set the scene, Section 1 briefly reviews the literature on the adoption of communication technology and Section 2 reviews the literature on the relationship between the use of communications and strength of ties. Section 3 brings all the elements together and sets out the structure and dynamics of the agent-based model.

5.1 The Adoption of New Technology

Adoption of new technology is essentially a social process, which can be only partly explained by economics (Douglas & Isherwood, 1996, pp.xx-xxvii; Rogers, 2003, p.289). Economists can look at the short term impact of changes in prices and incomes but not the longer term question of why some goods come to be adopted by the majority of the population while others do not (Douglas and Isherwood, 1979, p.99). Economists Deaton and Muellbauer (1985, pp.71-72) found it “sobering to discover” that “the most important and obvious shifts in the pattern of demand in Britain in this century…cannot apparently be explained in terms of changes in real income or price structure”. And Stermersch & Tellis (2004) suggested, adoption “takeoff patterns may be predominantly driven by cultural traits of countries”.

General adoption process

The diffusion of innovations of all kinds has been studied since the mid-twentieth century and a considerable literature has developed (see Rogers, 2003, pp.39-101). Rogers (2003, pp.168-208) identified five stages in the adoption process:

1. Obtain knowledge about the existence of the product, how it is used and how it works. This is a cognitive process. Those who know first about an innovation tend to be more educated, of higher social status, more exposed to mass media and have a wider circle of social contacts.
2. Be persuaded. This is an affective process. At this stage personal contacts are more important than mass media as people seek information to reduce their uncertainty about the innovation.
3. Decide either to accept or reject the innovation. The decision to adopt is more likely if it is possible to try out the innovation and adopt gradually. The rejection process has been less well studied (ibid, pp.110-111), but presumably those who initially reject an innovation may re-visit their decision at a later time.

4. Implement the decision by obtaining and using the innovation. It is at this stage that what Rogers calls "re-invention" occurs, whereby people adapt the innovation for their own purpose. If "re-invention" is possible, then the innovation is more likely to be adopted.
5. Seek confirmation. Disenchantment may set in leading to rejection. This is more common among later adopters, possibly because they have the wrong expectations or find they cannot afford to use it.

Rogers (2003, pp.15-18) suggested that adoption will be faster:

- the greater the perceived 'relative advantage', pecuniary or in terms of status;
- the greater the compatibility with existing values of beliefs, previously introduced ideas and perceived needs;
- the less complex the product;
- the easier it is to try out or to adopt in stages and
- the more it can be seen.

On the basis of many studies over many years of many different types of innovations, Rogers (2003, pp.281-2) divided adopters into five groups; innovators, early adopters, early majority, late majority and laggards.

- Innovators account for 2½ percent of the population. They have wide social networks, financial resources and technical knowledge but they are not necessarily respected within their social system. They can be likened to Simmel's stranger (ibid, pp.42, 290-1), i.e. people who have weak ties to the system.
- Early adopters account for 13½ percent of the population. They are somewhat similar to innovators but are more embedded in the social system, being opinion leaders and respected role models (ibid, pp.316-319) for whom status is likely to be important (ibid, p.251). Early adopters tend to face low benefits and high costs (Markus, 1987).
- The early majority comprise 34 percent of the population. They interact frequently with their peers but are rarely opinion leaders.
- The late majority account for another 34 percent and are persuaded to adopt by peer pressure although they have limited resources.

- Laggards comprise the last 16 percent of the population, and tend to interact with other laggards.

Compared to later adopters, in general early adopters can be characterised by their socio-economic characteristics, personality and communicative behaviour:

- Socio-economic characteristics. Early adopters are better educated, of higher social status, and more likely to be upwardly mobile and wealthy (Rogers, 2003, p.288).
- Personality. Early adopters have greater empathy, are better able to deal with abstractions and be more rational (in the sense of being able to use the most effective means of attaining a desired end), have more favourable attitudes to change and to science, are better able to cope with risk and uncertainty, have higher aspirations and are less dogmatic and less fatalistic (in the sense of feeling they are able to control their own future) (ibid, pp.289-90).
- Communicative behaviour. Early adopters have wider social networks and greater social participation, as well as greater exposure to mass media and as a result have greater knowledge and understanding of innovations (ibid, pp.290-1). In particular, Markus (1987) pointed out that "active communication originators" and those who travel and have time pressures benefit most from interactive media.

Rogers reported that "there is inconsistent evidence about the relationship between age and innovativeness" and suggested that those with higher income are more likely to buy innovations because they can afford the risk and maybe older people can better afford the risks of innovation (Rogers, 2003, p.288). But as discussed in Chapter 2, others (Douglas and Isherwood, 1979 pp.99, 121-2; Urry, 2000, p.110) argued that the rich are buying time.

Network effects

The adoption of new communication technologies differs from that of items such as washing machines for example because of "network externalities", that is, the value of joining the network depends on the number of people who have already joined (Varian, 2003, p.631). When a network is small, there is little value to be had from joining it. But the more people who join, the more valuable it is to join. Metcalfe's Law says that "the value of a communications network is proportional to the square of the number of its users" (Briscoe et al, 2006). Essentially "the idea is that a network is more valuable the more people you can call or write to" (ibid). That is intuitive but why the square of the number of users? As explained in Chapter 3, if there is a network comprising n members, each can make $n - 1$ connections and if all those connections are of equal value, then the value of the network is proportional to $n(n - 1)$, or approximately n^2 if n is large. What is meant by 'value' is, however, unclear. Metcalfe (cited in Briscoe et al, 2006) said that the original idea was that a critical mass must be reached before networks 'pay'. At the macro level, this could be interpreted as the value of a phone network to, say, a potential corporate buyer but corporate mergers are not the subject of this thesis. At the micro level, it is possible to identify at least two types of 'value':

- the value to an individual already in the network of an additional person joining the network: what Markus (1987) called "reciprocal interdependence"
- the value of joining a network to an individual who has not yet joined.

These values will only depend on the total number of nodes in the network if all connections are of equal value. Yet in practice these values will depend on whether the individuals' friends and family are on the network; the fact that there may be a million, or even a billion, on the network is not directly relevant, other than by increasing the likelihood that friends and family are connected.

However, Reed (1999) argued that it is not necessary for a person to actually make a connection for it to have value; simply having the potential to create that connection provides the value, such as to be able to call for help. Furthermore Reed argued that the value of a communication network increases much faster than Metcalfe suggested because it enables the formation of groups. (Details in Box 5.1.1.) Cushman (2007) suggested that the value implied in Reed's Law will rarely be obtained because only a few of the potential groups will form; and that "the actual 'real' curve may be somewhere between Metcalfe's and Reed's curves" although the number of different identities any one individual has online would make Reed's Law even more dramatic, or implausible.

Box 5.1.1: Mathematics of Reed's Law.

Reed (1999) argued that the value of a communications network increases with the number of subscribers in three ways:
- Linearly: to contact "a fixed, small set of friends and family"
- Quadratically: the potential to contact everyone else on the network, following Metcalfe's original formulation
- Exponentially: by providing "group forming networks".

According to Reed, "the number of non-trivial subsets that can be formed from a set of n members is $2^n - n - 1$, which grows as 2^n.Thus the value of a network can be written as

$$an + bn^2 + c2^n$$

where a, b and c are constants, with b "much smaller than a" and presumably, c much smaller than b. As n increases, the quadratic and then exponential come to dominate. But 2^n rises very quickly indeed as n rises: for example, if n equals only 100, then 2^n is about 10^{30}. Thus for the formula to make any sense at all, c would have to be very, very small indeed.

In contrast to Reed, Briscoe et al (2006) argued that even Metcalfe's Law produced too high a value. They noted that if Metcalfe's Law held there would be a very large incentive for phone companies to merge, but this has not happened; and argued that "the fundamental flaw underlying both Metcalfe's and Reed's Laws is the assignment of equal value to all connections or groups". Instead, based on data on the geographical distribution of physical mail, they proposed a formulation implying a much slower rise in value as the number of connections rises than does Metcalfe's Law (Briscoe et al, 2006). (Details in Box 5.1.2.) While Metcalfe's Law implies additional interaction as more people join a network, Briscoe's Law implies this effect is very weak. Whatever the precise mathematical form of the law, the basic point is that the more people who are connected to a communications network, the more attractive it becomes for others to join.

Box 5.1.2: Mathematics of Briscoe's Law.

Briscoe et al (2006) proposed that "the value of a network of size n grows in proportion to $n\log(n)$ based on Zipf's Law. Their argument is as follows.

The amount of communication with each of your email contacts will decline according to Zipf's Law. Thus if the person you communicate with most – ranked 1 – is given an arbitrary value of 1 unit, you will have half as much communication with the person ranked second, a third as much with the third and so on. Thus the total value will be $1+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}\ldots$ and so on. Thus if there were a network of 100 people, it would be 'worth' just over 5 units to any one individual; but just 18 connections would provide two thirds of this 'value'. Now, according to Briscoe et al this series

$$1+\tfrac{1}{2}+\tfrac{1}{3}+\tfrac{1}{4}\ldots {}^{1}/_{(n-1)}$$

approaches $\log(n)$. As each of the n members of the network also derive this value, the total value of the network is $n\log(n)$.

Thus "micro (individual) inputs" are related to "macro (community) outcomes" (Markus, 1987). Rogers (2003, Fig. 8-5) therefore suggested that there is a more pronounced "S" curve for "interactive innovations" than for others: a slower start followed by a more rapid growth to saturation. (For a technical discussion, see Varian, 2003, pp.631-635 and Arthur, 1989).

Markus (1987) asserted that

> "there are only two stable states of interactive medium usage in a community: all or nothing. Either usage will spread to all members of a community … or no one will use the medium (for communications internal to the community) either because no one started using it or because usage fell off in the absence of reciprocity".

Furthermore, she argued that universal adoption will be more likely when the interactive medium:

- has "active notification capabilities" such as mail handed to the recipient or a flashing light on a phone to indicate a voicemail message, rather than having to rely on people to check email inboxes for example.
- requires "low skill and effort", and in particular, when voice-based rather than text.
- has low start up and operational costs.

Valente (1995, p.130) argued that "interactive communication technologies represent media of high interdependence, and as such, are subject to higher network, threshold and critical mass effects" where critical mass is "the minimum number of participants needed to sustain a diffusion process" (Valente, 1995, p.79). Furthermore "in most diffusion situations there exists a pool of individuals who are central in the network who represent the potential critical mass" (Valente, 1995, p.87); and that once this group adopts, given sufficient other network properties such as density, and weak ties, a critical mass is created.

There is, however, disagreement about the size of this critical mass. Rogers (2003, p.360) suggests that "take off" typically occurs when between 5 and 20 percent have adopted.

Markus (1987) suggested the “tipping point” might be around 16 percent. However, Valente (1995, p.83) suggested that it might be around 50 percent adoption for phones as people will then feel that it is necessary to have one when so many others have.

Although the structure of the social network is very important to the diffusion process, there have apparently been few studies on the importance of the social structure (Rogers, 2003 p.25). An individual is more likely to adopt an innovation if those in their own personal networks have adopted (Rogers, 2003, p.359). Homophilous networks encourage diffusion between members of the group but they can become a barrier to diffusion because they may offer no new information while heterophilous contact – likely through weak links – is vital to bridge between groups (Oliver et al, 1985; Markus, 1987; Rogers, 2003, pp.306-7 & 338-340). However, when Cointet & Roth (2007) explored the impact of different network structures on the transmission of ideas, they were unable to decide which features – such as clustering, degree or size – were important.

Threshold model

Valente (1995 pp.70-71) argued that because the adoption experiences of others may not be observable and adoption of an innovation involves risk, people look to those to whom they are directly linked or “very near” “in status” for information on costs and benefits. Thus he argued that threshold models of diffusion should use the concept of “personal network exposure” i.e. “proportion of adopters in personal network at a given point in time”. In threshold models an individual’s action depends on the number of others in their personal network who have adopted: the lower the individual’s threshold, the earlier the adoption (Valente, 1995, pp.64-66). Therefore, an “an individual’s threshold is the proportion of an individual’s personal network who must adopt before he or she does, and thresholds are the exposure level necessary for an individual to adopt an innovation”. Those who adopt before anyone else in their network have zero threshold: those who wait until most of their personal network adopt have high threshold (ibid, p.78). People with the same threshold may adopt at different times because they have different levels of exposure, which are determined by their personal network (ibid, p.74). Valente (1995, p.120) showed that exposure is not highly correlated with adoption because it works through thresholds which are

> "distributed through the population so that individuals with low thresholds adopt when their exposure is low. Individuals with low thresholds do not wait until their exposure is higher to adopt, but rather adopt when their exposure is low. Consequently, exposure cannot influence adoption in the traditional manner in which higher exposure is expected to be correlated with adoption. Rather, exposure influences adoption by enabling individuals to reach their thresholds".

Thus innovators adopt before "critical mass" is reached because they have a lower threshold (Rogers, 2003, p.357).

However, "there is a dynamic interaction between the individual-level threshold and the system-level critical mass point, and between the critical mass and the thresholds" (Valente, 1995, p.92). More specifically (Valente, 1995, p.71):

> "The proportion of adopters in an individual's personal network generally increases during diffusion because over time more individuals adopt the innovation. The increase in the proportion of adopters in the individuals' personal networks does not occur uniformly in the system but rather increases according to the structure of the system defined by the pattern of communication in the network".

Essentially, on average the more people adopt, the more adopters there will be in an individual's personal network, which both increases exposure and reduces the threshold, by reducing the perceived risk of adoption. If that individual then adopts, their neighbour's exposure is increased and the system level adoption is increased. But the system level cannot be easily seen by an individual, though it may be partially visible through media. The larger the system the more likely it is more likely to cover those with whom you want to communicate, as Valente noted.

Threshold models are particularly suited to agent-based modelling because they can deal with both the local, micro – the individual and the personal network – and the global, macro, or society. Agent-based models of the diffusion of technology adoption have been developed alongside models of the diffusion of ideas and the spread of epidemics. The basic idea underlying such models is that ideas, information, knowledge or germs are transmitted from one individual to another. Two basic types of dynamics are identified

(Cointet & Roth, 2007: 5.1; Kempe et al, 2003):

- threshold models: people adopt if a given number or proportion of their neighbours adopt
- cascade models: people have a given probability of adopting after interacting with an informed neighbour.

Both involve interaction with neighbours and in both cases, parameters can adapt over time: for example thresholds can change and the probability of adopting in the cascade model can change (Cointet & Roth, 2007, para 5.14). Thus the cascade model could be regarded as a special case of the threshold model.

Examples

Two examples illustrate the points discussed:

- "early history of telephone use in the United States":

  "The first telephone subscribers bought telephones in pairs, along with a telephone line to connect, for example, an office to a factory, a home to an office…Many of these early subscribers later failed to see the value of a switched service that would allow them to reach all other subscribers: They were already communicating with their important others. However, once enough people were recruited to the new switched service, 'interconnection' of isolated networks proceeded rapidly". (Markus, 1987.)
- The fax machine was first introduced in the 1960s but was slow and expensive (Rogers, 2003, p.345). The average price of the machines in the US fell dramatically in the early 1980s from over 2,000 US$ in to under 500 US$ (Varian, 2003, p.636). The cost of using a fax also fell so that it was cheaper to fax a single page than to post it (Rogers, 2003, p.345). Rogers (ibid) suggests that "critical mass" occurred in the US about 1987. The number sold rose from a couple of hundred thousand a year in the early 1980s to over 2 million by 1990 (Varian, 2003, p.636).

As noted in the discussion of Metcalfe's Law, there is little point in adopting a communication technology if it cannot be used. The next Section turns to the use of communications.

5.2 Use of Communications

This Section starts by examining the effect of communications on travel, then discusses the relationship between communications and strength of ties.

Communications and travel

The key question posed in the Introduction was "Are communications and transport substitutes or complements?" The information on expenditure presented in Chapter 2 suggested that they were complements rather than substitutes. Nevertheless, there appears to be a widespread view that they are substitutes.

In economics, 'substitute' and 'complement' have very precise meanings:

- good X is a substitute for good Y if I choose to buy good X when I previously bought Y: for example, if I send a letter when previously I would have visited, the letter has been substituted for the visit.
- good X complements good Y if as a result of buying more of good X I buy more of good Y: for example, I must buy both envelopes and stamps to send a letter so envelopes and stamps are complements. If I write a letter to arrange a visit, then the letter and visit are complementary.

However, this economists' use of the words 'substitute' and 'complement' seems to be rather different to the sociological or everyday use of the terms. The 'absent-presence' concept, what Peters (2000, p.139) described as "communication without embodiment", illustrates this second use of the terms. Starting with letters, Henkin (2007, pp.110 & 134) described how miners in the Californian Gold Rush and the soldiers in the American Civil War saw writing a letter as having a conversation with someone who is not present. Ayrton (1901) referred to a "dreamland and ghostland" in relation to then-future mobile phones, and this has been picked up in the modern mobile phone literature (for example, Licoppe & Smorelda, 2005). Writing a letter or talking on a mobile is seen as a substitute for seeing the person addressed. But in these cases, seeing the person addressed is simply not an available option. This means that communication is not a substitute for travel in the economic sense, which is about the choice between options. (In welfare economics, there is the idea of 'second-best' in which a situation is not optimal but some conditions of optimality are met. Maybe communication by letter or mobile is a 'second best solution' because you have to decide whether a letter or a phone call is better than no communication.) Thus the idea that communication and travel are substitutes is so pervasive, I suggest, because the word 'substitute' is not being in the economic sense but in this broader sociological sense.

There is also a time dimension which has implications for the dynamics of the relationship between communications and travel. Communication substitutes for travel in the sociological sense in the short term, but in the longer term complements in the economic sense. In the short term, people have more contact with those with whom they are already in contact but who they cannot, at that particular time, see face-to-face: this is substitution in the sociological sense. This ability to keep in contact prolongs the relationships that would otherwise have faded and thus increases the desire to travel when possible. This is complementarity in the economic sense: the demand for both travel and communication rises.

The Foresight report (2006a, p.9) noted that there might be a role for "virtual communications" to reduce the demand for transport but there is, however, little support for this substitution hypothesis. The Foresight report itself also noted (2006b, p.23) that:

> "it is well established that increasing connectivity drives increasing need for face-to-face communication. Relationships that are sustained by telecommunications usually create reasons to meet in person."

Urry (2000, p.75) too argued that travel has increased despite "the proliferation of communication devices that might substitute for travel" due to the way "social life is apparently networked" and argued that occasional face-to-face meetings are essential, especially to maintain weak ties (Urry, 2003b). Adams (1999) argued that societies' use of the phone and the internet is highly correlated with physical mobility and that:

> "The hope that extensive use of telecommunications will obviate the need for travel and the movement of goods, rests upon a decoupling of the trends of electronic and physical mobility for which there is no precedent".

Communication and strength of ties

There is considerable evidence that new communication technologies increase the strength of already strong ties (Haythornwaite & Wellman, 1998; Schiano et al, 2002, Boase, 2008). Boase et al (2006 pp.11-12) distinguished between “core ties”, which represent very close relationships and “significant ties” which are weaker than core ties, but “more than acquaintance”. They then suggested that “people often feel obliged to contact their core ties by phone when they are not able to see them in person. By contrast, they feel less obliged to contact their significant ties by phone when in-person contact is not possible”. Others (such as Wellman et al, 1997; Martin & Yeung, 2006; Tillema et al, 2008) have noted that the importance of phones in maintaining relationships, especially strong ties.

Cummings et al (2002) reported that: “Frequency of communication across all three modalities [email, in person and telephone] was significantly related to the strength of relationship, both directly and once the partner’s gender, nature of the relations, length of relationship, and geographic distance between the parties were controlled statistically”. More recently Carrasco et al (2008a) have examined the relationship between personal networks and use of communications media and noted the importance email in maintaining contact in a way not facilitated by phones.

Distance matters. It has long been established that physical proximity increases the likelihood of friendships (Heider, 1958, pp.188-189; Cummings et al, 2006). Looking at the personal network beyond the household it appears that broadly about a quarter of those with close ties live very close (Fischer, 1982; Mok et al, 2007) and that non-kin tend to be geographically closer than kin. In particular, Coulthard et al (2002) reported that in 2000 just over half of British adults had close relatives living nearby and almost three quarters had close friends living nearby. In 2000, one fifth of people in Britain saw friends every day and three quarters, at least once a week; one in seven saw relatives daily and nearly two thirds, at least once a week (Coulthard et al, 2002, p.54). So “more friendship contact than kinship contact is local…Kinship relations are less local…

distance does not reduce social contact to the extent it does in friendship relations" (Quan-Haase & Wellman, 2002 p.305). Face-to-face communication requires proximity: if people do not live very short distances apart, this means they must travel. The frequency of face-to-face meetings falls dramatically with increasing distances (Warnes, 1985; Smoreda & Thomas, 2001; Quan-Haase & Wellman, 2002 p.305; Licoppe & Smoreda, 2005; Larsen et al, 2006 p.112; Frei & Axhausen, 2009).

Phone calls, fixed or mobile, become less frequent but of longer duration as distance increases (Wellman, 1996; Quan-Haase & Wellman, 2002 p.305; Coulthard, 2003; Licoppe & Smoreda, 2000 & 2005; Lacohee and Anderson, 2001; Larsen et al, 2006 p.112; Lambiotte et al, 2008). The relationship between spatial distance and contact by other means is less clear cut: the frequency of SMS and email contact seems to be little affected by distance and letters seem to be unaffected (Smoreda and Thomas, 2001; Frei & Axhausen, 2009). Because many close ties are local, this underlies the observation that technologies designed for long-distance communication tend to be used for local communication: what could be called 'the distance paradox'**.**

To sum up: in general, it appears that the stronger the ties and the smaller the distance, the more communication. Although distance reduces the frequency of contact, it increases the duration of the contact events that do take place. However, Axhausen (2003) suggested defining effort of maintaining contact in terms of time and money and postulated that that effort is distributed according to a power law so that "effort expended on any one person drops exponentially with that person's rank". A technological change may then bring about more intensive contact with the same people or contact with more people.

It was argued in Chapter 3 that social networks and communication networks are not the same and that the strength of social ties is not necessarily reflected in the frequency of communication. To address this problem, I define the 'intentional' personal network as those with whom an effort is made to maintain the relationship by communication and travel. In general for this group there is a direct relationship between strength of tie and communication: the stronger the tie, the more the contact, for a given distance. Most of those in the stronger zones discussed in Chapter 3 will belong in this group: kin and friends.

Taking into account the discussion in Chapter 3, I suggest that the typical intentional personal network will probably be around 30, with an average of five core ties. In contrast, what could be called the incidental group comprises those with whom we come into contact in the course of our daily lives, going to work, doing the shopping and so on. Contact with this 'incidental personal network' is thus a side-effect of other activities. This is not to say that this incidental group is unimportant: it contributes to our psychological well-being, our sense of belonging and so on. But for this group there is no direct relationship between strength of tie and frequency of contact. By definition these weak ties will be maintained by frequent contact, often face-to-face. Neighbours and co-workers who are not friends will be in the incidental group as contact is made with them in going about our daily business by virtue of their geographical proximity. Acquaintances are, by definition, incidental. No effort is made to seek them out although they may be greeted cordially. Their names may not even be known.

These two groups differ from Surra and Milardo's psychological and interactive networks (discussed in Chapter 3) in two important respects. First, in the intentional personal network, there is a direct relationship between strength of tie and communication whereas there is not in their psychological network. Second, unlike Surra and Milardo's two groups, there is no overlap between the intentional and incidental networks.

5.3 The Model

This Section starts by describing the general structure of the model. Next the environment and the properties of the agents are defined. Then two types of dynamic processes are described based on what happens when a new mode of communication appears. The dynamics are described with the aid of the Unified Modelling Language (UML) which sets out rules and conventions, such as shapes and line styles, to be used in diagrams.

General Structure

Following the discussions in the previous Chapters, especially Chapter 1, the model has three levels:

- The bottom level comprises individuals, or households, depending on the type of technology. Coleman (1994, p.4) argued that generally the individual should be the basic unit but that it may sometimes be appropriate to refer to households. Whichever is used, these represent the centre of a personal network.
- The middle level comprises the 'intentional personal network' as defined in the previous Section i.e. those with whom an effort is made to maintain the relationship by communication and travel and for whom the stronger the tie, the more the contact, given distance. As Boissevain (1974, p.25) said: "the concept of the personal network offers a concept of social dimension between …local and national level". In the context of Chapter 1, this middle level is related to, but is not the same as, Surra & Milardo's (1991) 'psychological network'; it also relates to Collins's (1987 p.196) "'mesostructure', the network of repeated encounters", and Habermas's "lifeworld".
- At the top is 'society', the level of macro observation, typically national level at which rules and regulations are set and aggregate communication and travel statistics are collected. In terms of the micro-macro debate, this is similar to Habermas's 'system'.

The top level is used for validating the model: the model itself comprises the bottom and middle levels.

The Environment

The model is based on the social circles model described in Chapter 4. In this model, the agents occupy a social space and the distance between them represents social distance. The social space in this context is taken as representing the intentional personal network discussed in the previous Section.

The Agents

Agents can represent individuals or households. They may have any of four types of attributes:

- demographic: age
- socio-economic characteristics: income and social class
- skills: ability to use new technology
- a personal network defined by social reach as set out in Chapter 4.

With the exception of social class, these characteristics may change over time:

- Agents age and die and new agents are born.
- Income may rise or fall.
- Skills may increase.
- The size and identity of an agent's personal network will change due to social shifting (as discussed in Chapter 4) and mortality.

Dynamics: Adoption

There are various ways of representing dynamics in the UML but here activity diagrams are used. Activity diagrams are "designed to be a simplified look at what happens" during a process (Schmuller, 1999, p.134) and comprise four basic elements:

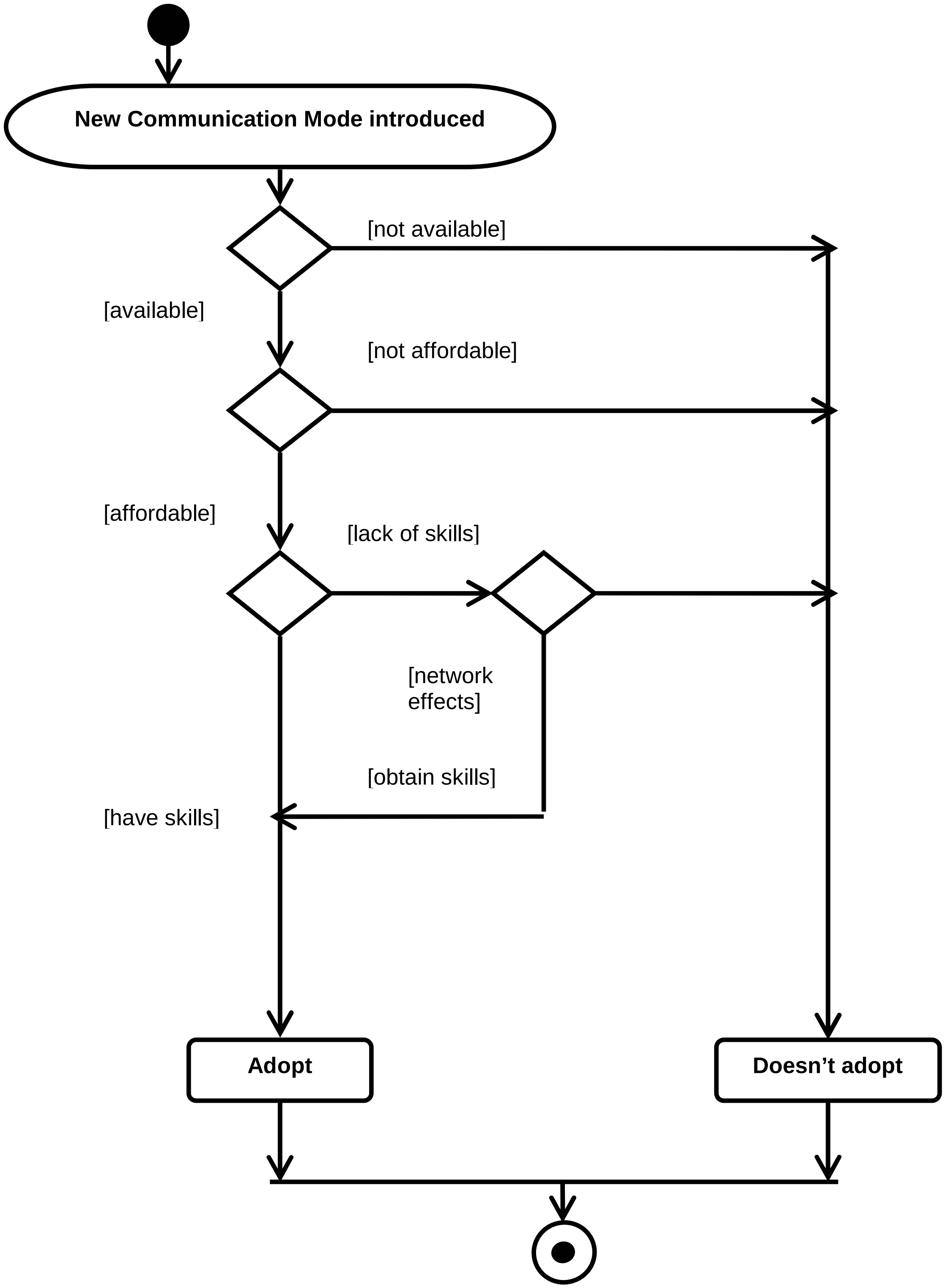
- the states of an object (shown by a rounded rectangle);
- a decision (shown by a diamond) with the options labelled;
- the activity (shown by a narrower, more rounded rectangle);
- the transition (shown by an arrow).

In addition, there are notes (shown in boxes edged with broken lines). On this basis, the adoption process is illustrated in Fig. 5.3.1. It has four key stages:

- Availability. Obviously, a new communication mode must be available to be adopted. Initially, a new mode may be available in only a restricted geographical area.
- Affordability. Affordability generally increases over time as the cost of new technology tends to fall and real incomes rise. Costs are not always simple to measure. In some cases, costs are only incurred at the point of use. In other cases, equipment has to be purchased or rented and perhaps a subscription paid. For example, postage has to be paid only when a letter is sent, and a fare paid when a rail journey is made. In contrast, a mobile phone has to be purchased and calls paid for either in advance or by monthly contract. Similarly, a car has to be bought and insured and its tank filled with petrol to make a journey.
- Skills. Skill requirements vary from none to high. It takes little skill to use a fixed line phone but to write a letter requires a reasonable degree of literacy.
- Network effects. Following Valente (1996), the two types of network effects are used:
    - the Personal Network Effect occurs when agents join a communications network if others in their personal network have already joined.
    - the Social Network Effect occurs when an agent adopts even if there are no adopters in their personal network but others in society have adopted.

  These network effects can add to the probability of adopting only if the mode is available and affordable and if the agent has the requisite skills. They can, however, act as an incentive to obtain those skills, hence the feedback loop.

Fig. 5.3.1: Activity diagram for general model: adoption.



Dynamics: Use

The use model is illustrated in Fig. 5.3.2: the introduction of a new mode of communication has seven effects: four affecting the pattern of communications and three affecting travel. (Detailed discussion of the evidence for these effects follows in the case studies.)

The four communication effects are:

- The social solidarity effect: a new communication mode will be used to send messages to those in the agent's personal network.
- The communication substitution effect: a new communication mode will result in reductions in use of older communication modes. This substitution effect partly offsets the social solidarity effect.
- New practices arise as a result of a new communication mode.
- The global village effect: named after McLuhan's idea that new communications technologies would increase the geographical spread of contacts – "the ability to interact with any person on the face of the globe" thereby creating the 'global village' (McLuhan & Powers, 1989, p.118). This effect increases the size of personal networks (in contrast to the first two effects which operated on the existing personal network). This is achieved in two possible ways: by enabling people to maintain contacts that would otherwise have been lost due to the cost and difficulty of communicating over spatial distance, and by creating new links.

The first two effects will be seen to some extent as soon as the new mode arrives: the last two are longer term effects. Overall, these four effects increase the number of messages sent.

Three further effects concern the interaction of communication and travel.

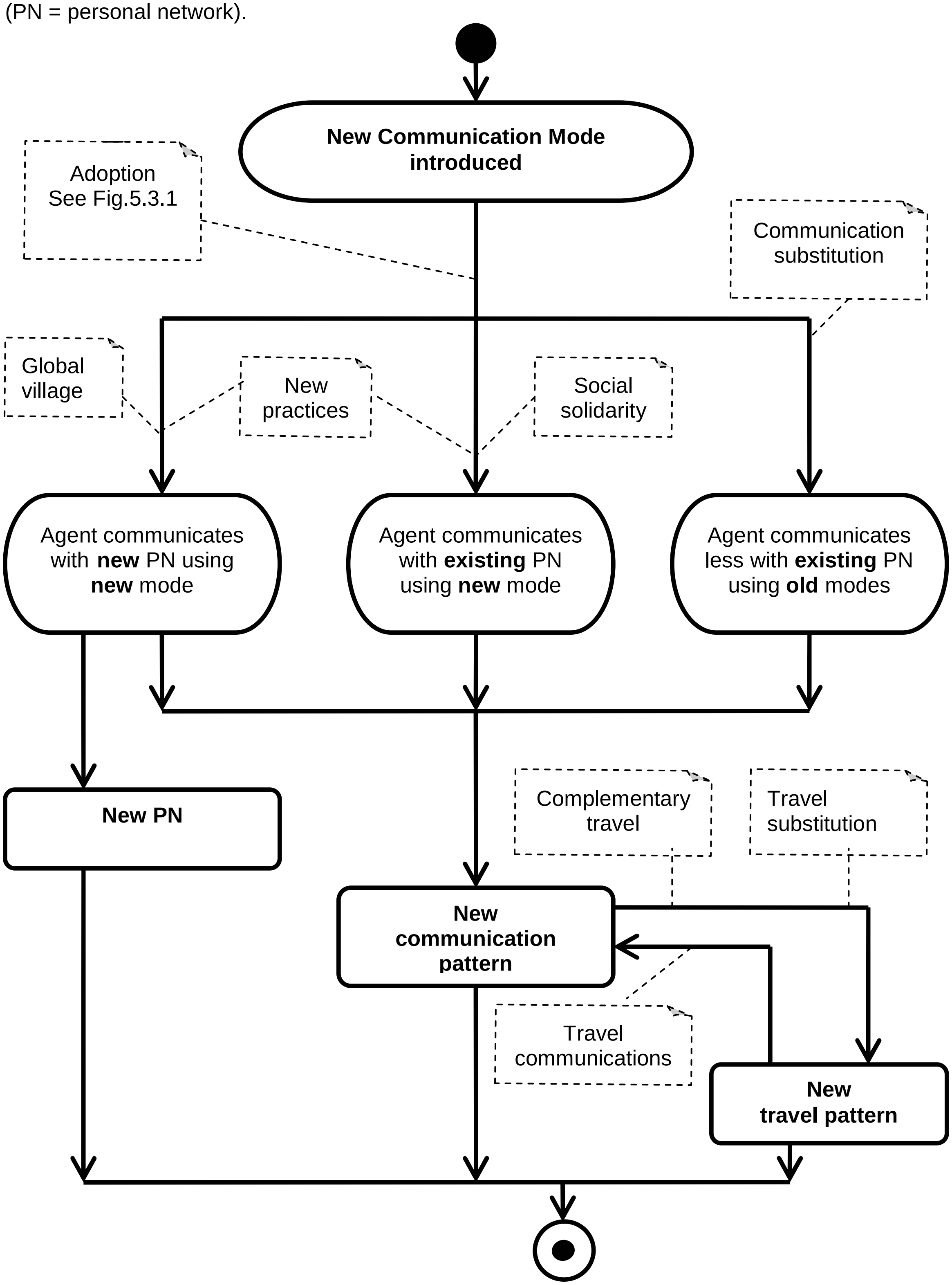
- **The complementary travel effect**: more communication results in more travel. While the Global Village Effect extends personal networks to those at greater distance and is therefore likely to encourage longer distance travel, local travel may also be increased. As noted above, the social solidarity effect results in more communication within the existing network and the existing network tends to be local. Thus both local and longer distance travel will increase as a result of more communications.
- **The travel communications effect:** more travel results in more communication. This can arise in at least two ways:
  - The planning effect. Communications are often about making plans (see for example Goldsmith & Baxter, 1996) and often travel plans (Foresight, 2006b, p.23).
  - The socialising effect. Travel creates a need or desire to communicate.
- **The travel substitution effect**: better, easier or cheaper communication modes reduce the need to travel.

The first two effects will increase travel; the third will reduce it.

The bottom line, both figuratively and literally in Fig. 5.3.2, is that the introduction of a new mode of communication results in a new personal network, a new communication pattern and a new travel pattern. Summing together the new personal networks, communication and travel patterns for each agent produces a set of new macro patterns.

The following three chapters set out case studies based on this general model.

Fig. 5.3.2: Activity diagram for general model: use.
(PN = personal network).



Chapter 6: Mail and Rail

This Chapter presents a case study of the adoption and use of mail and rail services in the nineteenth century, based on a variant of the two circle social network model described in Chapter 4. This case study focuses on the 73 years from 1840 to 1913. The start year of 1840 was chosen because that was the year in which the universal Penny Post was introduced. The end year of 1913 was chosen because the First World War, starting in 1914, caused a major discontinuity in economic and social life. This period is particularly interesting for communication and transport studies because for most people there were no choices available for long-distance communication and travel: communication was by mail and travel by rail, which also transported the mail. (Although telegraph and, later, the telephone were available, their use was limited to businesses and the wealthy.)

Data

Despite its remoteness in time, there is much information available about the period. The key sources are described below.

- Demographic and similar statistics

  The first population Census was undertaken in Great Britain in 1801 and was repeated every 10 years, collecting ever increasing amounts of information. There is some doubt as to the accuracy of the first two Censuses, but not later ones (Mitchell, 1971, p.2; Tillott, 1972, p.83). In addition the civil registration of births, marriages and deaths started in 1838, although it was probably not comprehensive until the 1860s or later in some places (Coleman & Salt, 1992, p.35; Mitchell, 1971, pp.2-3). The figures used here have been gleaned from various sources, especially Mitchell (1971 & 1988) and Coleman & Salt (1992).

- Economic statistics

  The two key sources are:

  - Mitchell's (1988) *British Historical Statistics*;
  - Feinstein's (1972) *National Income, Expenditure and Output of the United Kingdom: 1855-1965.*

- Mail

  In addition to Mitchell's (1988) *British Historical Statistics*, I have referred to three histories of the Post Office.

  - Lewins' (1864/2007) *Her Majesty's Mails: An Historical and Descriptive Account of the British Post Office*. Lewins appears to have been a Post Office employee (personal communication with British Postal Museum & Archive, 7 August 2008).
  - Robinson's (1953) *Britain's Post Office*. Robinson was an academic historian and the book was produced with the support of the Post Office.
  - Daunton's (1985) *Royal Mail: The Post Office since 1840*. Daunton was also an academic historian and the book was commissioned by the Post Office.

- Rail

  The railway industry was highly fragmented in the early years but as each railway required an Act of Parliament, there are records of the legal proceedings (Mitchell, 1971, p.216; Quinn, 2004, p.173; Ville, 2004, p.305; Wolmar, 2007). The founding of the railway clearing house in 1842 brought some co-ordination (Schivelbusch, 1986, p.29) and from 1843 "regular returns were published by the office of the Commissioner of Railways". According to Mitchell these returns were "reasonably reliable up to 1869 and perfectly so thereafter" (Mitchell, 1971, p.216). Again, the Chapter relies heavily on Mitchell's work. While most railway histories focus on technological and economic issues, Simmons' (1971) *The Victorian Railway* and Wolmar's (2007) *Fire and Steam* focus on social issues and are much quoted in this Chapter. General transport histories such as Bagwell's (1974) *The Transport Revolution from 1770* have also proved very useful.

Reference is made to many other texts and in particular, several chapters in Floud & Johnson's (2004) *Cambridge Economic History of Modern Britain*, *Volume 1, Industrialisation: 1700-1860* and *Volume 2: Economic Maturity, 1860-1939*.

Note that throughout this Chapter 'penny' refers to the old penny (*d*), of which there were 12 to the shilling and 240 to the pound. As a rough rule of thumb, to convert the prices in this Chapter to current values, multiple by 100. In other words, 1*d* was equivalent to about 40p today (1/240 x 100). (For more details, see Chapter 2.)

Outline of the Chapter

Section 1 discusses mobility in Britain before and during the industrial revolution. Section 2 focuses on travel and communications and ends with the stylised facts to be modelled. Section 3 presents the model on adoption, Section 4 extends the model to cover use and Section 5 concludes.

6.1 Mobility

Contrary to popular myth, there is considerable evidence to suggest that British society did not fit the gemeinshaft model and large nuclear families were not common in Britain prior to the industrial revolution and arrival of the railways. Rather, Britain was a mobile society.

Macfarlane (1978) argued that England's social structure was different to that of continental Europe before the industrial revolution due to different inheritance arrangements: in England, land passed from one individual to another rather than being held by a family as on the continent. This meant that in England those who did not inherit had to leave. Macfarlane (1978, p.78) reported:

> "historians have found evidence of very considerable geographical mobility and turnover from the sixteenth century onwards…They have noted that very great fluidity of the social structure, with rapid upward and downward social mobility….children moved away from home before marriage and often lived in separate villages".

Smith (1979, cited in Scott, 1991, pp.82-83) also rejected "the idea of a tightly knit organic community organized around kin and neighbours. The network structure…was…much looser". Analysis of parish registers and other records show the lack of persistence of surnames implying that there was significant geographical movement, in particular to London, from the sixteenth century. Studies based on linking nineteenth century Census records suggest a turnover rate of about 50 percent over 10 years (Schurer, 1991). (See, also for example, Coleman & Salt, 1992, pp.25-28; Laslett, 1983, pp.75-7; Macfarlane, 1978, pp.68-74).

Laslett (1972, pp.140-2) argued that average household size altered little during industrialisation, only changing at the start of the twentieth century and thus:

> "It is not true that most of our ancestors lived in extended families. It is not true that industrialisation brought the simple nuclear family with it." (Laslett, 1983, p.91).

Coleman (2000, p.76) made a similar point:

> "Contrary to popular sociological myth, there never was any time in recorded history when co-residential extended families were very common in Britain, either vertically extended (three or more generations) or horizontally (relatives outside the nuclear family). In 1861, 47 percent of Victorian households consisted of one or both parents with their children but no other relatives, exactly the same size as in 1961 and 1966".

And Humphries (2004) agreed. Nor were families very stable: "in the nineteenth century almost one marriage in three was a remarriage for one or both partners" due to death (Coleman, 2000, p.64).

By 1840, nearly half the population were living in towns and by 1911, this had risen to almost 80 percent as people left agriculture for the distributive trades and other activities (Coleman & Salt, 1992, p.41; Feinstein, 1972, Table 60; Wrigley, 2004, pp.91-92). For example:

- "Birthplace data from the 1841 census onwards show that only 40 percent of those aged over 20…had been born in the town they lived in." (Coleman & Salt, 1992, p.79).
- In 1851, Census data showed that half the adult populations of Stockport, Bolton and Manchester had been born "outside their boundaries": for Preston in Lancashire, then considered to be the most urbanised county in Britain, it was 70 percent (Anderson, 1971, pp.32-34).

This geographical mobility implied social mobility too. Thompson (1939/1973, p.166) told of the daughters of poor farm labourers who left their Oxfordshire hamlet to go into service, married in a "distant part of the country", and eventually became "quite prosperous". But inheritance of occupations remained high: a sample of English marriage registers dated 1839-43 indicated that half the grooms reported identical occupations to those of their fathers although there was considerable variation by occupation (Mitch, 2004, pp.336-7).

Furthermore, most migrants moved only short distances, except those going to the important urban markets like London (Anderson, 1971, p.37; Baines & Woods, 2004; Coleman & Salt, 1992, p.79). Anderson's study of Preston showed that "over 40 percent of the migrants had come less than 10 miles" (Anderson, 1971, p.37). More examples from 1851:

- "half of Liverpool's immigrants in 1851 came from Lancashire" (Coleman & Salt, 1992, p.79).
- A 2 percent sample drawn from the 1851 census found that 54 percent were living more than 2 kilometres from their place of birth in 1851 (Anderson, 1990, cited by Baines & Woods, 2004). In other words, almost half remained within 2 kilometres of their place of birth.

Moving within towns was also common, although often less than half a mile (Anderson, 1971 pp.41-2).

Migration was dominated by single people in their teens and young married couples (Anderson, 1971, p40; Baines & Woods, 2004; Thompson, 1939/1973, p.169). This was particularly so for those in rural areas, and for girls (Anderson, 1972, p.233; Horn, 2003, pp.13, 36-37; Thompson, 1939/1973, pp.155-7; Schurer, 1991). In the 1880s, one in three girls aged 15 to 20 was employed as a domestic servant, causing an imbalance in the rural population as the bulk of the vacancies were in the towns, especially London (Horn, 2004, pp.36-37, 53). Employers often preferred not to recruit local people as servants because they would reveal the families' secrets and girls were often sent 20 miles away, which also discouraged them from returning home (Horn, 2004, p.36). Furthermore "the turnover in servants was high…the average time spent at any one post was three years…the most mobile were the young servants, who as they acquired skills, changed jobs to move up the ladder" (Flanders, 2003, p.96).

There was also longer distance migration. Many people came to England from Ireland (then part of the United Kingdom): "in the 1850s, 3.5 percent of the British population were Irish" although by 1911, the proportion actually born in Ireland had fallen to 1.6 percent (Baines & Wood, 2004). Although data on international emigration and immigration for this period are available, Mitchell (1971, pp.3-4) reported that they are of poor quality. Also, it is important to look at net figures as from the 1870s, more than 40 percent of emigrants returned" (Baines & Wood, 2004). Coleman & Salt (1992, p.79) put the "net loss" from emigration at "about 1.2 million between 1841 and 1911". Finally, Baines & Woods (2004) noted that

> "many things that inhibit migration in the early twenty first century were of little consequence in the nineteenth, such as the location of good schools or elderly relatives. Most important the housing market must have been more open than today".

By way of illustration, some of the changes described above can be seen in my own family's history, shown in Box 6.1.1: stability at the same time as local and international migration, movement of servants, and how geographical and social mobility were related.

According to Sunderland (2007, p.85), between 1780 and 1880 informal networks were maintained by face-to-face meetings, correspondence, attendance at formal meetings and exchange of gifts. Anderson argued that "contact was typically maintained with home" through visiting and letter, noting that "many people were not daunted by the prospect of walking 20 miles in a day" (Anderson, 1971, pp.37, 159). For example, the girls who went into service would return once a year for their fortnight's holidays and in between they would send money home (Thompson 1939/1973, pp.165-6; Horn, 2003, p.6). Thompson (1939/1973, pp.166-7) recalled that some of the girls returned to marry "after several years of courtship, mostly conducted by letter", sent weekly. In my own family history visitors were recorded on Census nights, and not just in better-off families, but also in houses that must have been very overcrowded by modern standards. Thus when people migrated, they often maintained at least some of their social network at their place of origin.

To sum up, nineteenth century society was mobile. The new communications and transport technology meant that literate people could maintain at least some of their contacts when they moved. Given this mobility it is not surprising that by 1840 the mail and transport systems were already developed, as discussed in the next Section.

Box 6.1.1: Real examples from family history.

Stability

My father’s family, agricultural workers, stayed in the same village on the Oxfordshire-Warwickshire border: my great-great grandfather (b1820), great-grandfather (b1861) and grandfather (b1896) were all born in the same village.

Local migration

A great-great grandmother, daughter of a coal-miner, can be tracked through each of the Censuses from 1841, when she was just 2 years old, to 1901. She grew up in Glamorgan between Cardiff and Bridgend. By 1861, she was married and living about 50 miles away in Llanelli, Carmarthenshire. Between 1861 and 1871 she was widowed and remarried and by 1871 she was living in Pembrey, just 6 miles from Llanelli. Between 1871 and 1881 she was widowed again and moved 17 miles to Swansea, just 35 miles from where she grew up. There she stayed, although with different addresses, until at least 1901.

A great-grandmother (1863-1943) was born and raised in Merthyr Tydfil and migrated to Swansea, 30 miles away, where she married and remained for the rest of her life, albeit at different addresses.

Servants

A great-great grandfather living in London in 1861 had five servants: three were born in Essex – of whom two appear to be sisters – another was from Norfolk and the fifth from Kent. Ten years later, in 1871, only one of the five was still with the family.

Geographical and social mobility combined

A great-great-grandfather (b c1822) in Devon moved to industrial Swansea in the 1840s, possibly with his brothers, and was followed by his parents and sister in the 1850s, by which time his parents were in their late 50s. The journey is not as far as it sounds as, certainly in the 1850s, there was a regular ferry across the Bristol Channel from Ilfracombe to Swansea. He became an affluent tradesman, owning his own business.

Another great-great grandfather was a farmer’s son from north Wales (born c1821) who made his fortune in Italy and became a wealthy London businessman in the 1840s.

International migration

A great-grandfather (b c1851), came over from what is now the Republic of Ireland in the early 1880s, settling first in Wolverhampton before moving to London in the 1890s – an example of step-migration.

There are two examples of true international migration, both from Germany: a step great-great grandfather (b c1847) became a lead worker in south Wales; the other, a great-grandfather (b1854), a City merchant.

6.2 Communications and Transport

This Section describes the development of communications and transport in the nineteenth century: mail, telegraph and telephone, stagecoach and rail.

Mail

The 1765 Post Office Act introduced penny posts “for any City or Town and Suburbs thereof, and Places adjacent” (Robinson, 1953, pp.71, 125). They spread throughout the United Kingdom, often covering villages 20 miles away. By the mid-1830s “nearly 2,000 villages were served from over 700 post-towns” (Robinson, 1953, pp.126-7). From 1784, mail coaches replaced “foot- and horse- posts” (Robinson, 1953, pp.102-106), improving the service dramatically:

> “in the mid eighteenth century it would take more than a week for a London businessman to receive confirmation of an order sent to Birmingham, whereas after 1785 – when Royal mail coaches began to operate in the Midlands – a reply could be expected in two days” (May, 1987, p.34).

These services were supplemented by unofficial carriers who were regarded as smugglers by the Post Office because the Royal Mail had a legal monopoly on mail distribution.

The Royal Mail’s mail coach network in England and Wales centred on London, from where in 1835 28 coaches left “every night to carry mails to all parts of the island” (Robinson, 1953, p.116). This service was, however, expensive and the system complex, with letters often paid for by the recipient rather than the sender, and letters often taken to and collected from Post Offices (Daunton, 1985, pp.5-8). Within central London, postage was 2*d*: outer London cost an extra penny. Beyond London the cost increased with distance and the number of sheets of paper: to send a single a page from London to Brighton cost 8*d*, and to Liverpool 11*d* (Daunton, 1985, pp.6-7). As many agricultural labourers earned under £1 a week, 11*d* would have represented some 5 to 10 percent of their weekly wage (11 / 240).

The Post Office was profitable in the 1830s and this profit was regarded as a tax, and thus its activities were included in the then ongoing debate on taxation (Daunton, 1985, p.9). However, postal revenue was not growing with the population and trade and Rowland Hill argued in 1837 that this was because the Post Office's charges were hindering trade and "religious, moral and intellectual progress" (ibid). Hill contrasted the lack of growth in mail with the increase in the number of stage-coach travellers but Lewins (1864/2007, p.109) said "this fact need not be pressed, especially as one smart quarterly reviewer answered that, of course, the more men travelled, the less need of writing"! Lewins (1864/2007, p.115) added: "Mr Hill's proposals were instantly hailed with intense satisfaction, especially by the mercantile and manufacturing classes of the community". Indeed, in 1839, over 2,000 petitions in favour of the universal Penny Post containing over a quarter of a million names were sent to MPs (Robinson, 1953, p.144). In all, "no less than 5,000 petitions" were made (Lewins, 1864/2007, p.11).

Hill proposed a complete reform of the Post Office, affecting not just pricing but also collection and distribution, for example introducing prepayment and the first adhesive postage stamp, the now-famous Penny Black (Robinson, 1953, pp.139-150). In effect, Hill's reforms created the postal service as we know it today. One of the key assumptions underlying Hill's universal Penny Post proposal

> "was that the demand for the letter post was responsive to the rate charges, so that the reduction in the postage rate would induce an increase of five and a quarter times in the volume of traffic" (Daunton, 1985, p.20).

The extent of mail smuggling underlined the fact that demand for Royal Mail services would increase if the prices were lower (Lewins, 1864/2007, pp.118-121). However, the Post Office argued that

> "people…would not sit down and write letters simply because it had become cheaper, and demand was not as responsive to price so much as to increases in population and business" (Daunton, 1985, p.22).

The 1840 reform eliminated the problem of letter "smuggling" (Lewins, 1864/2007 pp.118-121) and following 1840 there was a dramatic increase in the amount of mail. Taking Mitchell's (1988) estimate that the Royal Mail carried 73 million letters in 1839, Hill's forecast that the volume of mail would increase by five and a quarter times – to about 380 million – was achieved by the early 1850s. This rise was not only in response to the significant reduction in price, but also in response to an improvement in service, including collection and payment methods. The volume of mail rose from 151 million items a year in 1840 to nearly 4 billion in 1913. However, the population of Great Britain slightly more than doubled between 1840 and 1913. The number of letters per person, including business-to-business, rose from 8 in 1840 to 75 in 1913, an almost tenfold increase (Mitchell, 1988; Robinson, 1953, p.221). No data has been found that distinguished business from consumer mail in this period but Daunton (1985, p.79) commented "Before the introduction of the Penny Post, most letters were probably sent business purposes, and there was subsequently an increase in personal correspondence".

Although the basic penny rate for a letter did not change throughout the period, two important changes occurred around 1870:

- the weight of a letter carried for one penny was doubled from ½ to 1 ounce. (Robinson, 1953, p.194). (Today the basic letter rate applies up to 60g or about 2 ounces.)
- the introduction of postcards with postage of just ½*d*.

Postcards proved immediately popular: over half a million cards passed through the main London Office on the first day and in the first full year 75 million were posted (British Postal Museum, 2009). They "exploded in popularity" from 1902 when picture postcards as we know them today were introduced (Postcard Traders Association, 2009). They were often associated with travel: Wolmar (2007, p.192) noted that around the turn of the century one of the railway companies "produced millions of postcards, sold through vending machines". Furthermore, my own analysis of 22 postcards sent to, and often from, members of a middle-class family between 1905 and 1910 found that 6 anticipated face-to-face-meetings. (Details in Box 6.4.3.)

Box 6.2.1: A small study of Edwardian postcards.

Twenty-two postcards were found in a family collection. They had been sent to, and often from, members of a middle-class family in South Wales between 1905 and 1910. Ages, relationships and circumstances of sender, recipient or both are known. There are 5 recipients - a mother and 4 daughters - and 14 senders including a son and 4 daughters.

12 of the messages are 'single purpose' and a further 5 are dual purpose. The remaining 5 messages fall in to more categories.

- 8 of the cards are solely or primarily about the sort of things we send cards for today, albeit not necessarily postcards, such as birthdays and get well messages.
- 7 refer to 'not writing' and appear to be alternatives to writing a letter e.g.:
    - Daughter away at work to mother at home: "Am very busy now. Will write you tomorrow Friday."
- 6 of the messages anticipate face-to-face meetings, e.g.:
    - Girl at college to sisters at home: "I am coming home in a few days"
    - Girl at home to sister away: "I am coming down Friday with mama."
- 5 of the messages are about keeping in touch, 'thinking of you', rather than apologising for not writing e.g.
    - Girl at college to a sister at home: "I hope this P.C. will make you think of me."

Other types of cards also became important:

- Valentines became "big business" following the 1840 postal reforms for although they had been popular before, they were now more widely affordable (British Postal Museum, 2009). Henkin (2007, p.148) noted how the arrival of the postal system in the US caused Valentine's Day to become popular.)
- Christmas cards: the first commercial Christmas card was produced in 1843 (British Postal Museum, 2009).

Telegraph and telephones

Optical telegraphy had been in use since the end of the eighteenth century (Headrick, 2000, pp.193-203). But the first electrical telegraph came into operation in 1839, the wires running along the railway from Paddington in central London to West Drayton (Marsden & Smith, 2005, p.194). By 1852 The Electric Telegraph Company "operated some 6,500 km of telegraph lines connecting London with over 200 British towns" (Huurdeman, 2003, p.106).

However, telegrams were expensive. In the 1840s, The Electric Telegraph Company charged 1*d* per mile for up to 50 miles, with decreasing charges for subsequent miles

(Kieve, 1973, p.66). Yet a letter cost only 1*d* irrespective of distance. By the early 1860s, a telegram of 20 words cost a shilling to send (Kieve, 1973, p.125) i.e. twelve times the cost of a letter. In 1885, the minimum price of a telegram was reduced to 6*d* (Robinson, 1953, p.203) but even this lower rate "precluded its use for private purposes except by the well-to-do" (Kieve, 1973, p.195-6). Consequently, "the telegraph had no direct bearing on the average Victorian's life" (Connected Earth, 2008). In 1854, only 13 percent of messages concerned 'family affairs', the majority being related to business, in particular, the stock exchange (Kieve, 1973, p.119). Data is incomplete prior to nationalisation of the telegraph industry in 1865, but by then 151 letters were sent for each telegram (Kieve, 1973, p.130) and Mitchell's (1988) data suggests that at best, in the 1880s and 1890s, 30 letters were sent for every telegram. Not only did the cost discourage users, but also the lack of privacy because of the need to use operators (Standage, 1999, p.122).

From the late 1870s, telephones competed with telegrams (Robinson, 1953, p.218): the first telephone exchange opened in 1879 (BT Archives, 2009) and public phones were available from 1884 (Connected Earth, 2009b). By 1910-12, there were some 600 thousand phones, i.e. 1 per 100 people (Casson, 1910/2007, p.87). Like the telegraph, telephones were then primarily used by businesses and were rarely found in homes, as will be discussed in Chapter 7. Facsimile transmissions (fax) were first invented in the 1840s but were not developed commercially (Huurdemann, 2003, pp.147 & 602).

So although both electrical telegraphy and telephony appeared during this period, they were primarily used by business and are not considered further in this Chapter.

Travel by Road

Before the railways were built, passenger transport was by road or coastal shipping (see Simmons, 1991, p.312; Hawke, 1970, p.43; Gerhold, 1996). In the late eighteenth and early nineteenth centuries two important changes occurred in road transport: improved road surfaces and improved carriages. The improvement in road surfaces came about both because of the technical changes introduced by Telford and MacAdam and because the introduction of the turnpike system meant that roads were better maintained (see for example Bagwell, 1974, p40). In carriage design the main innovation was the elliptical spring, patented in 1805, which resulted in carriages being able to carry more passengers, more comfortably (Bagwell, 1974, p.49). Thus, Bagwell (1974, p.43) estimated that

> "fifteen times as many people were travelling by stage coach in the mid 1830s as were doing so 40 years earlier. In 1835 700 mail coaches and 3,300 stage coaches were in regular service in Great Britain. Assuming an average of 8 passengers per trip (though many coaches could carry up to 16 persons) and 2,500 trips per week, the number of individual coach journeys made in the course of that year must have been over 10 million".

The growth is corroborated by the increase in stage-coach duty collected by the Inland Revenue (Bagwell, 1974, p.34).

Given that the population of Britain was about 17 million in 1835 (Mitchell, 1988), 10 million journeys implies that on average each person, including children, made 0.6 journeys a year.

Travel by coach was expensive: "each inside passenger travelling by coach paid from two and one-half pence to four pence per mile" although "outside fares averaged 60 per cent of inside ones" (Jackman, 1962, pp.343-6 & Appendix 6; Hawke, 1970, p44; Gerhold, 1996). To this had to be added the cost of meals and accommodation: for example, the fare from Edinburgh to London was £4 10*s*, but with "meals, tips and over-night stops" the total cost of the journey was "nearly £50" (Burnett, 1969, p.157), more than many earned in a year (Mitchell, 1988: and see Chapter 2). Travelling by coach was therefore almost certainly only undertaken by a minority. While it is likely that this minority made several journeys each year, the great majority of people made none. Nevertheless, the growth in coaching suggests that there was already a latent demand for increased travel when the railways appeared.

Travel by Rail

The first passenger carrying railway line opened between Manchester and Liverpool in 1830 and it was a commercial success (Ville, 2004; Wolmar, 2007).

> "With very few exceptions, whenever a new line was opened to traffic there was a spectacular increase in the number of persons travelling along the route served compared with the numbers previously using the road…..By the mid-1830s parliamentary committees examining proposals for railway Bills took it as axiomatic that, once a railway was opened, the number of persons travelling by train would be at least double the number who had previously travelled on foot, by coach or by any other road vehicle" (Bagwell, 1974, p.107).

Journeys per head grew from 1 per annum in 1843 to 35 in 1913. However, although the number of journeys increased, the average distance travelled fell (Hawke, 1970, p.31). The modern measure of passenger miles (i.e. miles travelled by passengers) does not seem to be available although Mitchell (1988) reported passenger train miles (i.e. miles travelled by passenger trains). Thomas (2004) said "railway carriages transported five times as many passengers in 1870 as twenty years earlier: but since most of the new customers were shorter-distance travellers, the impact on passenger miles was less". This means that the increase in the number of journeys recorded probably overstates the growth in travel. (Note that these figures do not include tram journeys which Simmons (1991, p.317) suggested reduced rate of growth in rail travel, although arguably trams were used for shorter journeys, generally within towns, rather the long-distance inter-urban travel.)

By the early 1840s, the railways had replaced the mail coaches (Robinson, 1953, p.118) and by 1843 there were 22 million passenger journeys each year by rail (Mitchell, 1988) compared with the estimated 10 million journeys by coach in 1835 (discussed above). Despite this increase in travel, in 1839 Robert Stephenson told the Select Committee on Railways that there was "a class of people who [had] not yet had the advantage from the railways which they ought, that is the labouring classes" (cited in Bagwell, 1974, p.109). This changed with Gladstone's 1844 *Railway Regulation Act,* which even provided the legal means for future nationalisation although this was never used (Harris, 2004, p.214;

Wolmar, 2007, p.78). It became "better known as the Cheap Trains Act" (May, 1987, p.13) because Section IV of the Act introduced the Parliamentary trains which secured for "the poorer Class of Travellers the Means of travelling by Railway at moderate Fares, and in Carriages in which they may be protected from the Weather". One train a day was to run "at an average Rate of Speed of not less than Twelve Miles an Hour for the whole Distance travelled on the Railway including Stoppages". The passengers were to "be provided with Seats". "The Fare or Charge for each Third Class passenger by such a Train shall not exceed One Penny for each Mile travelled". For comparison, fares for second class travel were about 1½*d* per mile; for first class, 2*d* to 3*d* per mile (Wolmar, 2007, p.126). This Act appears to have been part of a raft of reforms that occurred around that time in response to "the spread of social distress and economic upheaval …[that] created what soon came to be called the Condition of England question" (Thomson, 1950, p.43). (Details in Box 6.2.2.)

Box 6.2.2: Reforms and the "Condition of England".

There were riots in 1839 following Parliament's rejection of the Chartists' request for universal male suffrage and other reforms. In 1844 Engels published *The Condition of the Working Class in England* and, at the other end of the political spectrum, in 1845 Disreali published *Sybil or The Two Nations* in which he aimed "to illustrate - the Condition of the People" and denied any exaggeration in the dreadful conditions he described (Disreali, 1845/1981, Preface). In 1848, Marx and Engels published *The Communist Manifesto*, which Taylor described as "rooted in the circumstances of its time", including "the coming revolutions of 1848" in France, Germany, Austria and Italy (Taylor, 1967, p.47; Trevelyan, 1942/1972, p.582).

Against this background, there was a raft of social legislation in the 1830s and 1840s, such as:

- the 1832 Reform Act, extending suffrage
- the 1833 Factory Act, regulating child labour;
- the 1833 Slave Emancipation Act;
- the reform of the Poor Law in 1834;
- the 1842 Mines Act, prohibiting the employment of women and young children in the mines;
- the repeal of the Corn Laws in 1846 as a result of a food crisis and
- the 1847 Ten Hours Act, limiting the working hours for women and children

(Trevelyan, 1942/1976, pp.556-7; Thomson, 1950, pp.46-89).

Simmons (1991, pp.320-321) argued that the 1844 *Railway Regulation Act* "unquestionably stimulated a very large growth of cheap travelling". Between 1843 and 1845, the number of passenger railway journeys increased by 40 percent, although this growth was no doubt due in part to the expansion of the network: the length of railway routes rose by nearly 20 percent (Mitchell, 1988). By 1846, "almost 10%" of journeys were in the Parliamentary trains (Simmons, 1991, pp.320-321) and “within five years, more than 50 percent of passengers were paying … a penny per mile” (Wolmar, 2007, p.78). Between 1849 and 1870 “the number of third class passengers increased by nearly six times whereas the increase in first and second class was fourfold”. Bagwell (1974, pp.108-9) attributed this increase to the introduction of the Parliamentary train. Hawke (1970, pp.37 & 359) claimed that from 1840 to 1870 “the main growth point of the passenger traffic was in the third and parliamentary classes”.

Much passenger traffic appears to have been for private rather than business purposes: Simmons argued (1991, p.321) that “passenger traffic was largely a pleasure trade”. However, the Parliamentary trains became “famous for their inconvenience, discomfort and snail-like pace” (Faith, 1994, p.79), running at inconvenient times (Wolmar, 2007, p.126). Simmons reported (1991, p.321) that after 1850 there was little evidence of the better-off travelling on the longer distance cheap trains: businessmen would have been unlikely to choose to spend 16 hours travelling to Liverpool on a Parliamentary train when they could have gone by second class in 6 hours. Using data provided by Hawke, I estimate that in 1865 half the passenger mileage was accounted for at fares of 1*d* a mile or lower. So the growth in third and Parliamentary traffic was predominantly private travel. Wolmar (2007, p.131) reported that “trains were largely used by the middle and upper classes…while the poor were confined to an annual excursion to the seaside and the odd essential trip when they could afford the fares”.

The importance of mail to the social fabric of the country is evidenced by the Sunday service question. In 1850, the Lord’s Day Observance Society campaigned for a total shut-down of public services on Sundays and succeeded in getting mail deliveries stopped (Flanders, 2003, p.146). “There was an immediate outcry …The complete stoppage of collections and deliveries lasted only a few weeks” (Robinson, 1953, p.166). The Society had more success with the railway companies due to the low profitability of Sunday services, and the increasing need for Sunday maintenance: from 1870 about a fifth of the network was closed on Sundays and where services did run, they were reduced, despite complaints (Simmons, 1991, pp.282-289).

Stylised facts

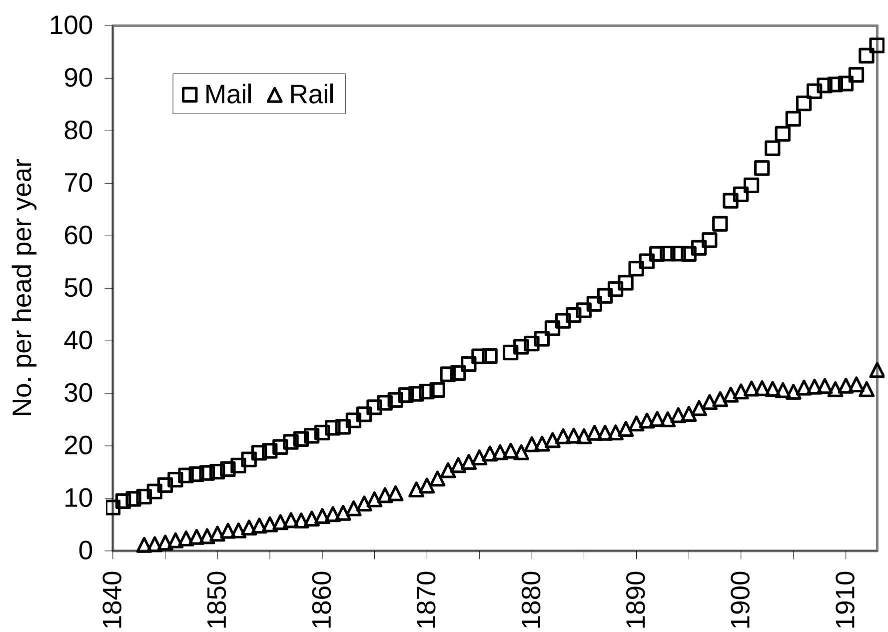
Following the procedure recommended by Gilbert (2007, p.127), the model building starts with a set of stylised facts. I suggest that there are two key facts to be explained, illustrated in Fig. 6.2.1.

- The number of letters per person rose from 8 in 1840 to 75 in 1913, almost a tenfold increase.
- Rail journeys per person per annum grew some thirtyfold: from 1 in 1843 to 35 in 1913.

(The growth rates are the same if the ratios are expressed in terms of the adult population rather than total population, but data for the adult population is only available for Census years.)

Following the structure set out in Chapter 5, first adoption and then use are modelled.

Fig. 6.2.1: Growth in mail and rail: GB: 1840/3 to 1913.



Source: Mitchell (1988). Gaps indicate where no data is available.

6.3 Model of Adoption

Following the structure of the general model of adoption described in Chapter 5, this Section starts with demography. Then availability, skills and affordability are discussed. The Section concludes by identifying the growth in the number of 'epistlers', the writers of epistles or letters (derived ultimately from the Greek *epistolē* (Oxford Dictionary, 1933/1979 & 2001)). Here epistlers are defined as those who were literate, had access to the mail system and could afford to use it.

Demography

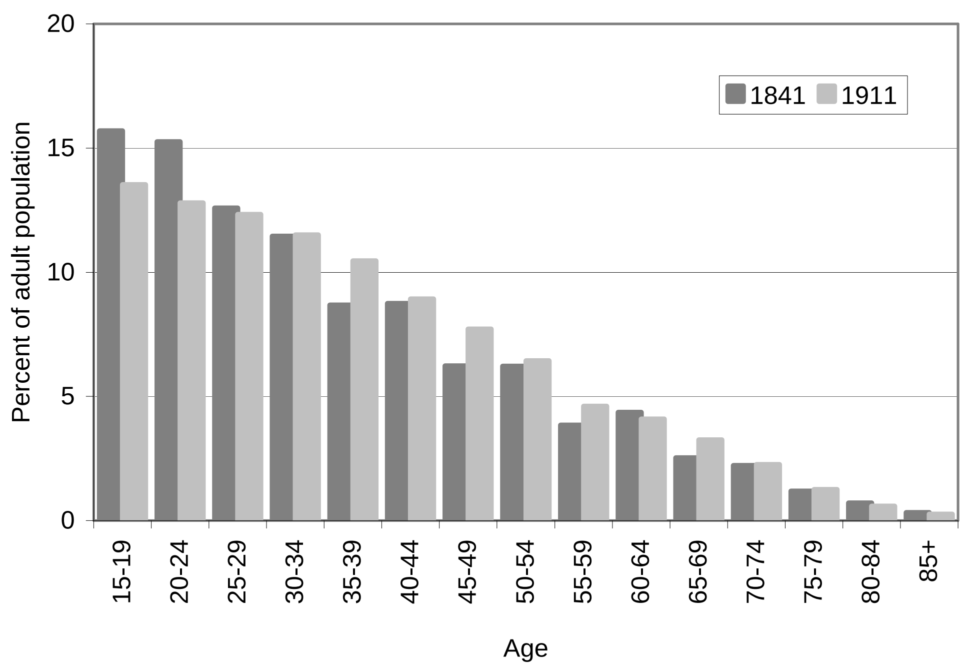
Between 1841 and 1911, the adult population of Great Britain (i.e. those aged 15 and over) more than doubled: for every 100 adults in 1841, there were 237 in 1911 (Mitchell, 1971, Table 40). However, increasing the number of agents in the social circles model described in Chapter 4 increases the size of personal networks (i.e. number within a given social reach) because the population density increases. But do personal networks increase in size as population increases? There are the limits on time, discussed in Chapter 2, and although there is little evidence that time constrains communication, that is in part because of the difficulty in collecting such evidence. In Chapter 3 it was noted that Wellman, Dunbar and others suggested that there appeared to be a limit on the size of personal networks. It would be possible to increase both the agents and the area so as to maintain the density at the same level. But it is not clear what the benefits of this approach would be while the computational costs and difficulties are very clear: for example:

- using some 2,400 agents instead of 1,000 will increase the time taken for each run (a valid consideration given NetLogo's slow speed);
- increasing the area of "the world" dynamically would require some complex programming and raise conceptual problems too, such as how to redistribute agents over the larger space.

It is therefore assumed that the size of personal networks does not increase with population growth. So rather than trying to replicate the population growth that occurred over this period, the number of agents is kept constant. Thus in effect, the model represents a sample of the population and the results should be compared with per capita rates, not totals.

To model population change in an agent-based model, some agents must 'die' and new agents be 'born'. As the aim of this model is not to investigate population dynamics, simplifying assumptions are made. The probability of dying rose with age from 5 per thousand for men aged 15-19 to 300 per thousand for those aged 85 and over. (The rates for women were similar: usually higher in the younger age bands due to deaths in childbirth but, for the survivors, lower in later life. For simplicity, an average of male and females rates is used.) However, to apply age-specific mortality rates requires agents be allocated an age. Fig.6.3.1 shows the age distributions of the adult population in 1841 and 1911.

Fig. 6.3.1: Age distribution of adult population: Great Britain: 1841 and 1911.



Source: Mitchell (1971, Table 13).

The age distribution and the mortality rates can be brought together to create a set of stylised demographic facts. An absolute age cut-off at 90 is used. Of course, a few people did live longer: data collected in 1821 suggested that some 7 thousand out of a British population of 12 million were aged 90 or over (Mitchell, 1971, p.11). But using a cut-off seems a reasonable simplification to avoid the possibility of agents reaching unrealistic ages. Box 6.3.1 provides the details.

Box 6.3.1: Demographic pseudo-code.

Initialisation

Create 1,000 agents and distribute them randomly across a space to give a density of almost 1%.

Divide the initial population into 4 age bands:

- young, to represent 15-24s: 30%
- prime, to represent 25-44s: 40%
- middle, to represent 55-64: 10%
- old, 65 to 85 inclusive: 7%

Allocate age to each agent. Within each age band, age is allocated randomly and uniformly. So, for example, among the 'young', 3% of agents will be allocated to each year from 15 to 24.

Execution

Agents age and die based on the mortality rates:

- young, 0.6%,
- prime, 1%
- middle, 2.5%
- old, 10%
- any agent reaching age 90 dies.

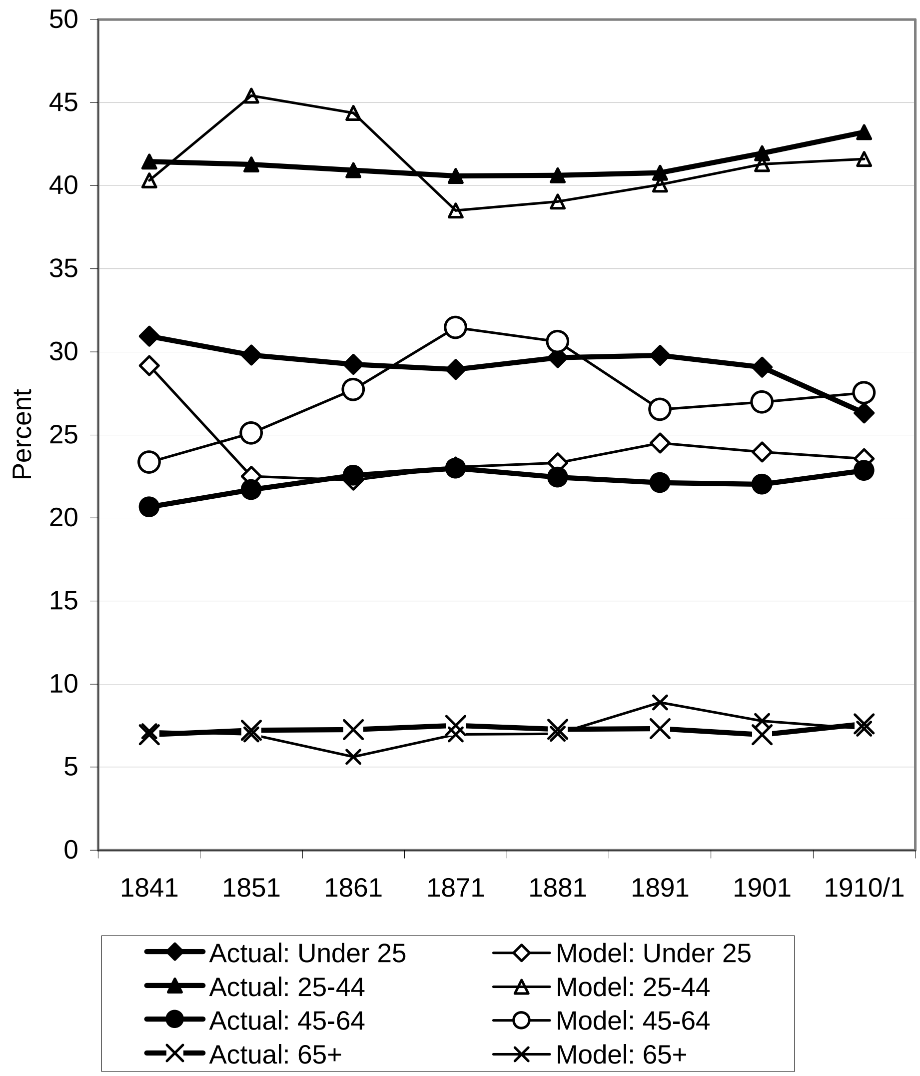
Calculate total number of deaths.

Create new agents depending on the number of deaths:
for the population to remain constant, the number of 'births' has to equal the number of deaths.

Set age of new agents to 15.

Fig. 6.3.2 shows how a model based on these stylised facts produces a population of agents with an age distribution that is broadly consistent with the observed demographics over the whole time period. By the end of the 70 year period modelled on average 99 percent of the agents had been replaced.

Fig. 6.3.2: Model results: age distribution: actual and model compared.



Availability

Prior to 1897, while some received up to 12 deliveries of mail a day (Daunton, 1985, p.47), others had no deliveries at all. Only from 1897 was there a regular delivery of mail "on at least two or three days a week to every house in the country" (ibid, p.44). Until then, those in more remote areas had to collect their letters from the post office or pay an additional fee. Thus the number of rural post offices was (as today) an important issue. In 1840, there were 3 thousand village post offices but by 1864 this had risen to 11 thousand (Lewins, 1864/2007, p.116). (In comparison, today there are 6½ thousand rural post offices (Postcomm, 2009b p.16), although the definition of 'rural' may have changed.) Thus by 1859 "about 93 percent of letters were delivered free of additional charge" (Daunton, 1985, p.44).

Rail was the key to mail services. "The Post Office was remarkably prompt at using the railways for the conveyance of mail", starting in 1830 (Daunton, 1985, p.122; Lewins, 1864/2007, p.214). By 1843, "the principal towns in the provinces" were already getting a second delivery of mail daily due to the railways (Lewins, 1864/2007, p.144). Dedicated mail trains were run overnight and passenger trains also carried mail during the day (ibid, pp.165-6). In 1864 Lewins (1864/2007, p.216) described London as "the heart of the postal system" with three of the four "arteries" running from there, supplemented by the "veins". The importance of London is further evidenced by the fact that a quarter of all UK letters were delivered in London in both 1850 and 1910/1 (Daunton, 1985, p.46) even though only 10 to 14 percent of the English population lived there (Coleman & Salt, 1992, p.28).

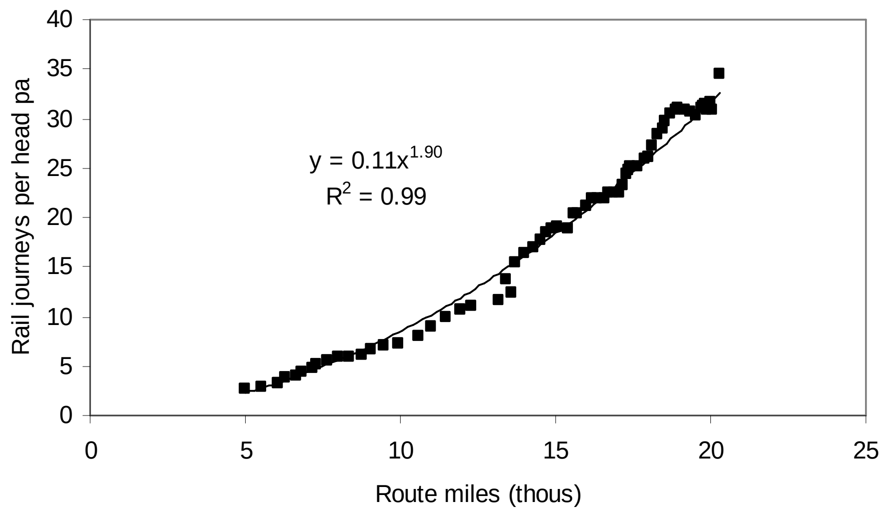
The railways expanded dramatically over the period. From 250 miles of railways in 1838 by 1843 there were 1,800 miles (Wolmar, 2007, p.75) with four major lines linking the main conurbations (London, Birmingham, Liverpool and Manchester) plus a line to Bristol. By 1845, it was possible to travel by rail from Exeter to Newcastle. Although there were lines in Wales and Scotland these were not yet linked to those in England (Dyos & Aldrcroft, 1971, Map 11). The left hand panel of Fig 6.3.3 shows the railway network in 1851, when it comprised just over 6 thousand miles, slightly over half what it is today; by then it was possible to travel by train from Plymouth to Aberdeen. By 1854, two thirds of the lines that were to form the Inter-City network had been built (Wolmar, 2007, p.108). Thus “by 1880 hardly any town of significance was more than walking distance from a station” (Wolmar, 2007, p.127); by “1900 the train offered the possibility of travelling to within a few miles of even small places” (Pooley et al, 2005, p.18), illustrated in the right hand panel of Fig. 6.3.3. “By 1914, there was barely a hamlet that was more than twenty miles from a station (Wolmar, 2007, p.127). The size of the network was then at its peak, some 20 thousand route miles, roughly twice its current length (Pooley et al, 2005, p.18; Root, 2000, p.440).

Fig. 6.3.3: Railway network in 1851 and 1900.

1851	**1900**
	
Source: Reproduced with permission from Wolmar, 2007 p xvi	Source: Reproduced with permission from Pooley et al, 2005 p19

Between 1848 and 1913, the route length of the railway system quadrupled, growing at over 4 percent a year to 1870 and 1 percent thereafter (Mitchell, 1988). Rail journeys per head increased with route miles according to a power law with an exponent of almost 2 (Fig 6.3.4), consistent with a network effect. Although by 1900 cars were appearing, for inter-urban travel trains were still the main means of transport (Pooley et al, 2005, p.18).

Fig. 6.3.4: Relationship between route length and journeys per head: 1848-1913.



Source of data: Mitchell (1988).

By 1851, half the population was urban, defined as living in towns of over 10,000; by 1881, two thirds and by the outbreak of the First World War, over three quarters. Even in the 1840s, many urban dwellers would have had access to both mail and rail services and from the 1850s probably all urban dwellers had access to both services. For the purposes of this model, it is therefore assumed that 40 percent of the population had access to rail services in 1840, rising to almost all by the start of the First World War. Because of the uncertainty about this assumption, the model also employs an alternative assumption that only those in urban areas had access to the railway network.

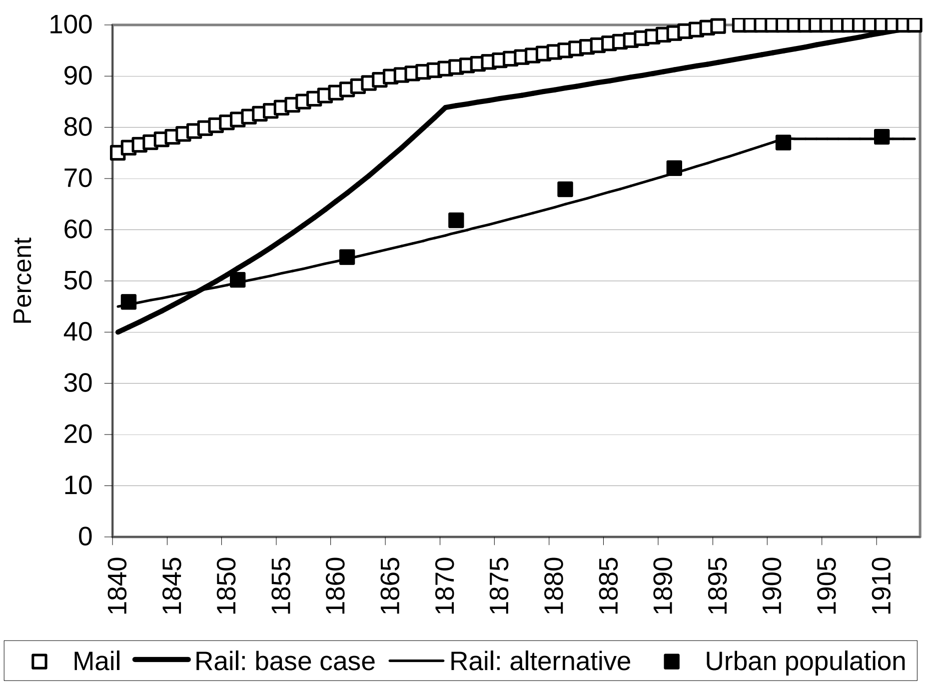
It seems reasonable to assume that all those who had access to rail also had access to mail services but that mail did reach further than the rail network. It is therefore assumed that three quarters had mail access initially, rising to 100 percent by 1897. But, again, because of the uncertainty of this, the model also includes the option for full mail access from the start. The details are in Box 6.3.2.

Box 6.3.2: Assumed growth in access to the mail and rail networks.

Mail		**Rail**	
Base case 1840 Annual growth: 1840-1865 1865-1897	 75% 0.7% 0.35%	Base case 1840 Annual growth: 1840-1870 1870-1910	 40% 2.5% 0.4%
Alternative	100% throughout	Alternative 1840 Annual growth: 1840-1900 1900-1910	 45% 0.9% 0%

Results

Percent of population that (a) had access to mail and (b) had access to rail (under base and alternative assumptions) and (c) lived in an urban area: 1840-1913



Source: Urban data for England and Wales: Coleman & Salt (1992, p.41)

Affordability

Those with access to the railways could not always afford to travel. For example Thompson (1939/1973, p.162) described the daughters of poor farm labourers going to their first jobs, setting off on their “first train journey, even though the hamlet was only three miles from the railway station”. As discussed in Chapter 2, there is little information on the distribution of income in the nineteenth century but Soltow (1980) estimated that the Gini coefficient was about a half. In 2007-08, the Gini coefficient based on income before taxes and benefits was also around a half (Barnard, 2009). The distributions of total income implied by these two Gini coefficients are shown in Table 6.3.1: for example, a Gini coefficient of a half implies that the top quintile have half the income while the bottom quintile have just 2½ percent. However because of the uncertainty, the model also includes the option of setting the Gini coefficient to one third, which is roughly the current level (as discussed in Chapter 2).

Table 6.3.1: Division of total income between quintiles by Gini coefficient.

	Gini coefficient	
	Approx half	Approx a third
Bottom quintile	2.5%	7.5%
Lower quintile	7.5%	12.5%
Middle quintile	15.0%	15.0%
Upper quintile	25.0%	20.0%
Top quintile	50.0%	45.0%
Total	100.0%	100.0%

Based on Jones (2008).

The model divides agents into quintiles and allocates income within each quintile on the basis of the distribution shown in the left hand column of Table 6.3.1 for the base case. For the very bottom quintile, a minimum is set. For the top quintile, a distribution is used that produces considerable variation in the maximum income. With a Gini coefficient of about a half, 63 percent of agents have less than average income and the median income is 75 percent of the average. The details of the model are set out in Box 6.3.3 and its results in Fig. 6.3.5.

Box 6.3.3: Allocating income in the model.

Explanation

The income figure is an index number, with the initial average set at around 100. It does not represent pounds.

Total income of 100,000 is allocated among 1,000 agents to ensure that the average income is around 100. (It actually ranges from 97 to 102). The agents are divided into 5 quintiles and the income is allocated according to the proportions set out in Table 6.3.1.
E.g. with the Gini coefficient of about a half, 15% of the total income – 15,000 units – is spread between the 200 agents in the middle quintile, producing an average of income of 75, which is achieved by allocating incomes randomly between 61 and 90.

The minimum income is set at 10. No maximum is set and this can vary considerably (from some 500 to 1,000) with an average of 678.

	Gini coefficient	
	Approx half	Approx a third
Bottom quintile	10-15	10-60
Lower quintile	16-60	61-65
Middle quintile	61-90	66-85
Upper quintile	91-160	86-115
Top quintile	Over 160	Over 115

Pseudo-code

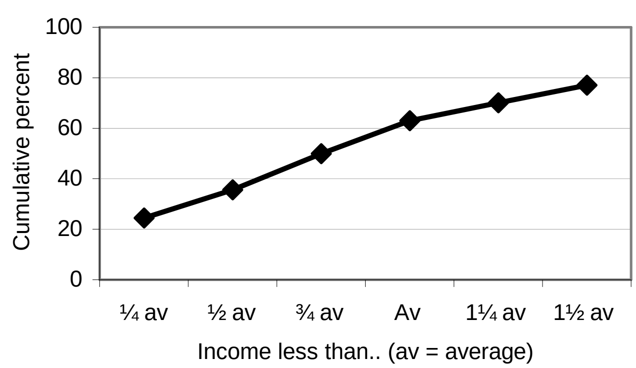
Allocate 200 agents each to bottom, lower, middle, upper and top income groups.

Set the range of income for each group on the basis of the Gini coefficient and the ranges given in the table above.

Allocate income randomly within each quintile group except for the top quintile where a random-exponential distribution is used with a mean of 90 for a Gini coefficient of about a half (and 110 for a coefficient of about a third).

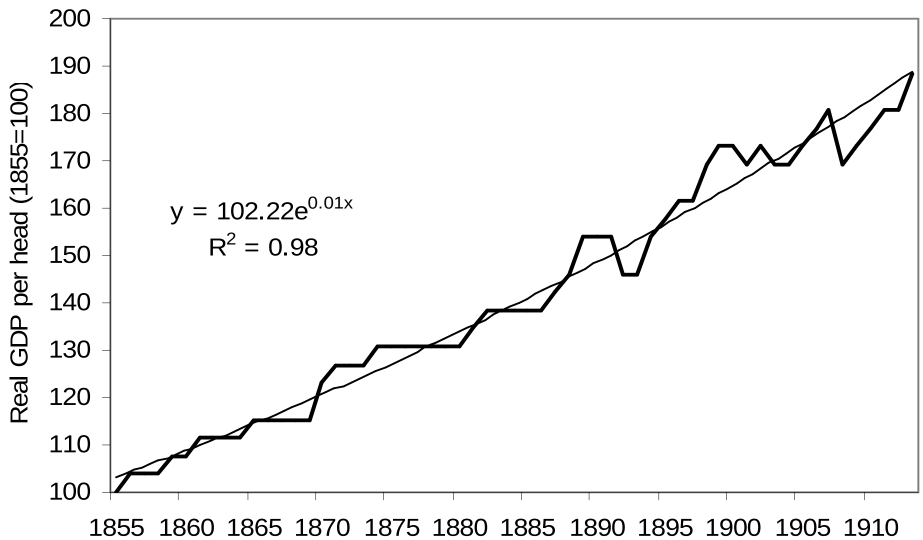
Fig. 6.3.5: Model results: distribution of income with the Gini coefficient of about a half.

Income	Percent
Below ¼ average	24.5
¼ to ½ average	11.1
½ to ¾ average	14.4
¾ to average	13.0
Average to 1¼ average	7.1
1¼ to 1½ average	7.1
1½ to 1¾ average	5.9
1½ to twice average	4.2
More than twice average	12.9
Total	100.0



During the period, incomes grew. On average from 1855 to 1910, real GDP per head grew by one percent a year (as shown in Fig. 6.3.6). Agents' incomes are therefore raised by one percent a year. This means each year, more agents can afford to adopt mail and rail services. In the model an affordability threshold is set and agents whose income exceeds that threshold are deemed able to afford the new services.

Fig. 6.3.6: Real GDP per head: UK: 1855-1913.



Source of data: Feinstein (1972).

But at what level of income should the affordability allowance be set? It is arguable that a higher threshold should be set for rail than for mail because undertaking a journey, even on the Parliamentary train, would be less affordable than sending a letter. Someone just above the poverty line might be able to afford a penny for a stamp, but not 5 shillings for a 60 mile round-trip rail journey. But because of the lack of data and for simplicity, just one threshold is used. It was established in Chapter 2 that by the end of the period a quarter could still not afford mail and rail services. What is not clear is how many could afford these services at the start of the period. Certainly the middle and upper classes, who accounted for around a fifth of the population, could afford them. But, it would appear from the rail history discussed above, so could some of those who were less well off.

Given that by the end of the period a quarter could not afford the services, then Fig. 6.3.5 suggests that the threshold was about a quarter of average income. As incomes roughly doubled over the period, then the affordability would have been about half average income at the start. As indicated in Fig. 6.3.5, one third had an income below this level and so a threshold set at this level would have enabled just under two-thirds to participate initially.

Affordability has been taken as an absolute rather than a relative measure, set on the basis of Rowntree's definition of poverty, based on the "maintenance of physical efficiency" (discussed in Chapter 2). The idea is that as economies grow, the poor can afford things that were previously the preserve of the rich. This is not to say that these people are not still relatively poor compared to others in the society, but that the poor can increasingly afford to send letters and to travel, albeit not as much as those who are better-off. The model handles this as follows. The affordability threshold represents a limit below which there was nothing to spare for non-essentials such as letters, cards and travel. As discretionary income increased – the income above this basic threshold – more could be spent on luxuries. For example, the doubling of real incomes means that those on average incomes in 1910 would have had three times the discretionary income that those on average incomes enjoyed in 1840 (as illustrated in Box 6.3.4).

Box 6.3.4: Illustration of increase in real discretionary income.

Index: average real income in 1840 = 100	**1840**	**1910**
Average income	100	200
Less the affordability threshold	50	50
Equals discretionary income	50	150

Skills

Access and sufficient income were not the only requirements to be met to use the mail services. People also had to be literate. Schofield (1973, cited in Mitch, 2004, pp.353-5) reckoned that by the end of the 18th century, all "gentry and professionals" and "officials etc" were literate as were most in the retail trades; and by 1830 70 percent of men were literate. Sanderson (1972) suggested that "by the end of the 1830s the younger generation possessed a higher degree of literacy than their parents". But literacy was often measured by the ability to sign one's name on a marriage certificate (Stone, 1969). It does not mean that people could write letters or even read them. Stone (1969) reported that "in the 1840s the ratio between the two varied between one to two and two to three". For example early in Queen Victoria's reign "79 percent of Northumberland and Durham miners could read, and about half of them could write" (Wilson, 2003, p.363). In 1843, 71 percent of the workers of a bleaching company in Bolton were literate, and by 1868-9 in Blackburn, 85 to 95 per cent of cotton workers could read and write (Sunderland, 2007, p.103). "The high and rising literacy rates fostered letter writing" (ibid).

Stone (1969) claimed that by the late nineteenth century "the ratios between name signing and adequate reading capacity and between reading capacity and writing capacity tended rapidly to converge". Nevertheless, just before the First World War Pember Reeves (1913/1979, pp.12, 15) found that among poor working class women of child-bearing age in London, 8 of the 31 women she interviewed could not read or write. She noted that the older women and

> "those who had had no reason to use a pencil after leaving school… had completely lost the power of connecting knowledge which might be in their minds with marks made by their hand on a piece of paper".

However, Lewins (1864/2007, pp.135-6) noted that the cheap mail system was an encouragement to learn to read and write. Henkin (2005, pp.25-26) made the same point in respect of the United States.

Table 6.3.2 brings together several data sources to estimate the extent of literacy. It suggests that while the total population doubled, the literate adult population may have increased fivefold.

Table 6.3.2: Estimated literacy: GB: 1840-1910.

		1840	1850	1860	1870	1880	1890	1900	1910
Population									
Total population, GB (mil)	(1)	18.3	20.6	23.0	25.8	29.4	32.8	36.7	40.5
% adults	(2)	*65*	*65*	*65*	*64*	*64*	*65*	*68*	*69*
Adult population, GB (mil)		**11.9**	**13.4**	**14.9**	**16.5**	**18.8**	**21.4**	**24.8**	**28.0**
Literacy									
Adult male literacy (%)	(3)	*66*	*69*	*74*	*80*	*86*	*93*	*97*	*97*
Adult female literacy (%)	(4)	*50*	*60*	*70*	*80*	*86*	*93*	*97*	*97*
Literacy rate for all adults (%)	(5)	*58*	*64*	*72*	*80*	*86*	*93*	*97*	*97*
Literate adults (mil)		6.9	8.6	10.7	13.2	16.1	19.9	24.0	27.2
% of literate adults who can write	(6)	*67*	*70*	*75*	*80*	*85*	*90*	*95*	*95*
Adults capable of writing									
- mil		**4.6**	**6.0**	**8.0**	**10.6**	**13.7**	**17.9**	**22.8**	**25.8**
- %		*39*	*45*	*54*	*64*	*73*	*84*	*92*	*92*

Notes
(1) Mitchell (1988).
(2) Based on UK data: Feinstein (1972). Adult means aged 15 and over.
(3) Based on Stone (1969) for England & Wales. Literate means able to sign name.
(4) Based on Mitch 2004: 344.
(5) 48% of the adult population were male (Feinstein, 1972).
(6) Based on Stone (1969), Wilson (2003), Pember-Reeves (1913/1979) & Bell (1907/1981).

In the model, it is assumed that initially 40 percent are literate in line with the estimate in Table 6.3.2. Further, it is assumed that all of those in the top quintile of the income distribution are literate and literacy is randomly distributed among those who are poorer. Literacy is assumed to spread primarily through the demographic process: as older agents die they are replaced by young agents who are more likely to be literate. The probability of a new, young agent being literate increases by 2.5 percentage points a year up to a maximum of 95 percent, which is reached by the early 1860s.

However, given the evidence that the introduction of the Penny Post encouraged literacy, it is also assumed that a few illiterates become literate due to contact with others, through the personal network effect. Although the evidence suggested that some who left school literate lost the skill through lack of practice, once literate, agents are assumed to remain literate. (Details in Box 6.3.5.) As shown in Table 6.3.7, this model closely reproduces the estimated growth in literacy shown in Table 6.3.2.

Box 6.3.5: Modelling increasing literacy.

Each year 1 percent of those
- with mail access and
- able to afford to use it and
- who are close to epistlers themselves

become literate.

'Close' is defined as being within a social reach of 10, which produces an average close personal network of 3, although a few have none in their network while others may have more than 5 as shown on the right.

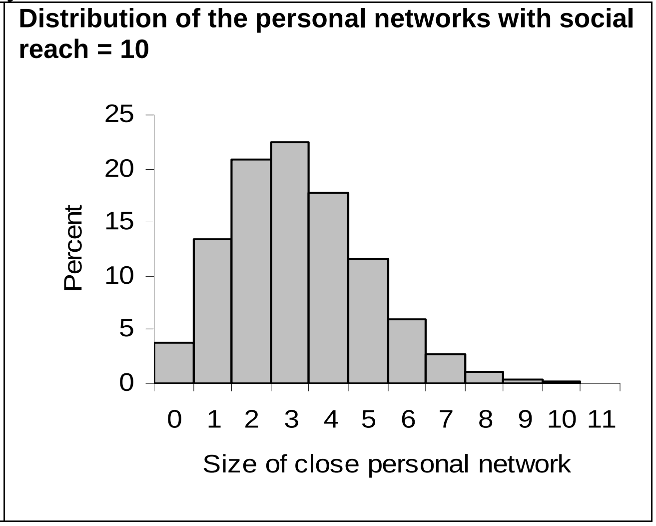
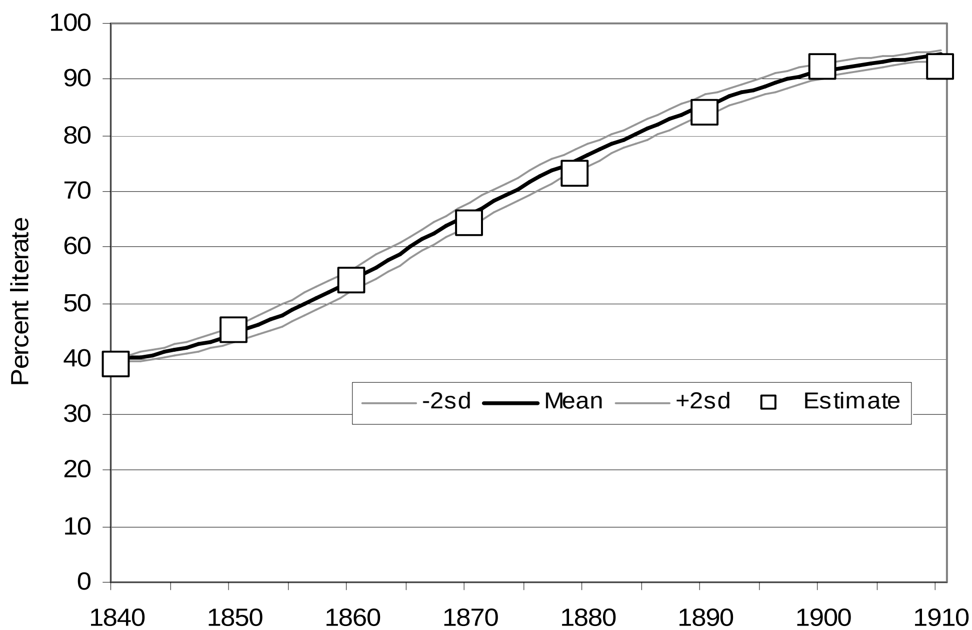


Fig. 6.3.7: Model results: written literacy rate: estimate and model compared



Note: Estimate based on Table 6.3.2

Summary of the adoption model

Box 6.3.6 summarises the adoption model.

Box 6.3.6: Summary of the adoption model

Population
1,000 agents are used to represent the adult population, aged 15 and over.
The population remains constant: agents who die, based on nineteenth century mortality rates, are replaced by 15 year olds. (Details in Box 6.3.1.)

Access (Details in Box 6.3.2.)
Mail: 75 percent have mail access initially, reaching 100 percent by 1897. (The alternative assumption is that there was 100 percent mail access throughout.)
Rail: 40 percent have rail access in 1840 rising to 98 percent by 1910. (The alternative assumption is that rail access grew with urbanisation: from 45 percent in 1840 to 77 percent in 1900 after which the rate did not change.)

Affordability
Incomes are distributed according to a Gini coefficient of about a half. (Details in Box 6.3.3.)
Affordability is determined by a threshold set initially at 50 percent of average income.
Incomes grow at 1 percent a year. (Prices do not change.)

Literacy
Initially 40 percent are literate, including all those in the top income quintile. The balance is allocated randomly across the poorer agents.
The literacy rate of new (young) agents rises by 2.5 percent each year to a maximum level of 95 percent.
Each year a few illiterates become literate. (Details in Box 6.3.5)

Results

The model combines all the assumptions made about demography, economic changes, the spread of access to mail services and of literacy to produce an estimate of the growth in the number of 'epistlers', defined as those who are literate with access to the mail system and able to afford to use it. The model suggests that the proportion of epistlers roughly trebled from just under a quarter to about 7 out of 10 by 1910. Although it was not necessary to be literate to use the rail network, it is the relationship between mail and rail that is of interest. To examine this, those epistlers who also had access to the rail network will be referred to as the 'travelling epistlers'. The proportion of travelling epistlers increased sixfold: from about 1 in 8 to about 7 out of 10 by 1910. The proportion of travelling epistlers grew faster than the proportion of epistlers because the rail network was less accessible initially. (Details in Fig 6.3.8.)

Fig. 6.3.8: Model results: epistlers and travelling epistlers.

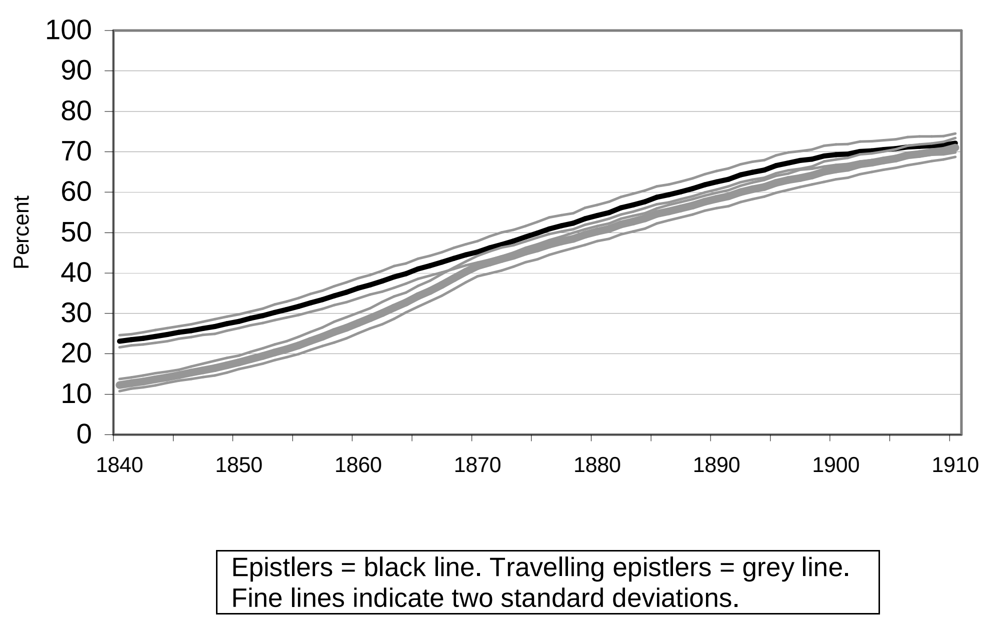
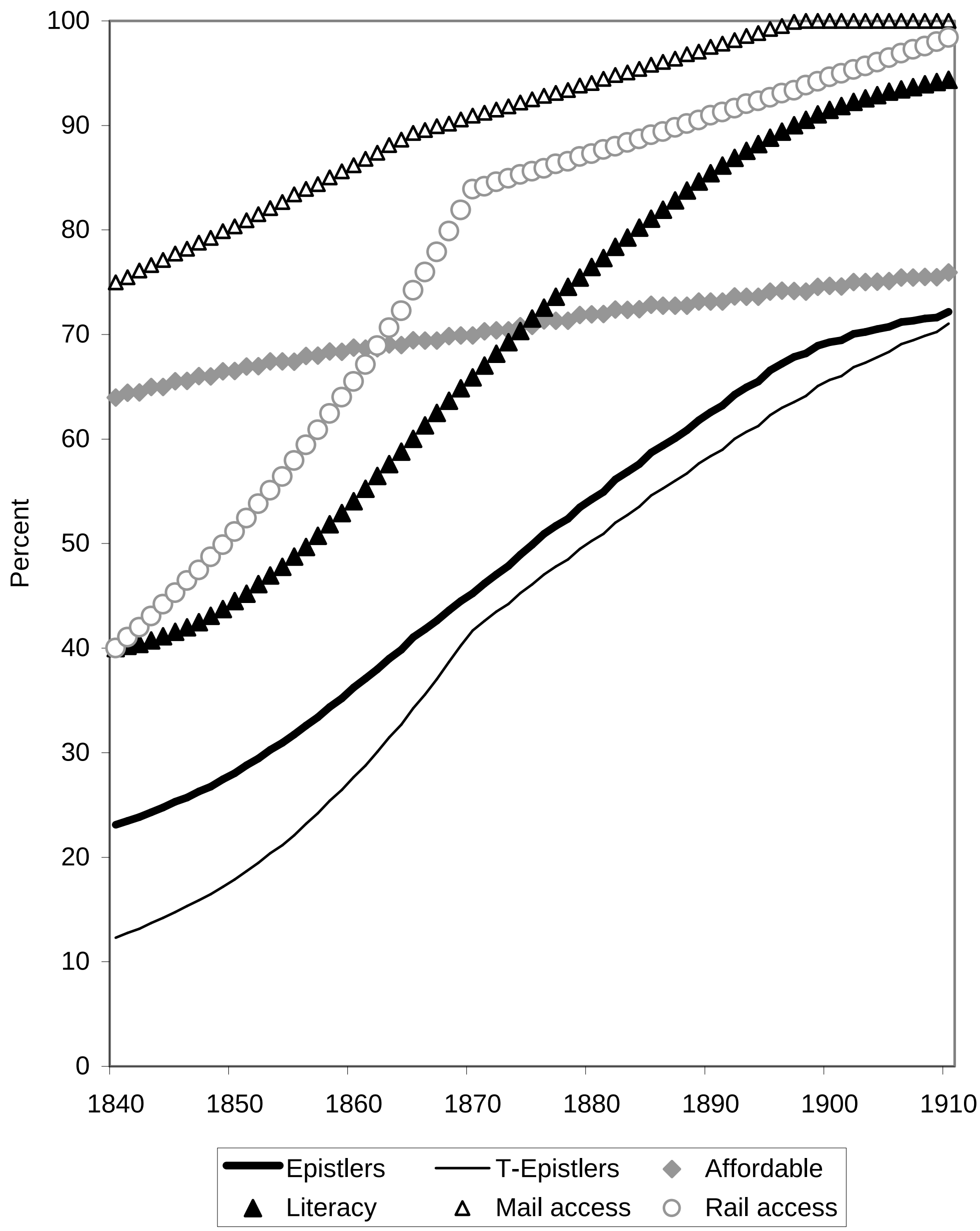


Fig. 6.3.8 can be regarded as an adoption curve in that mail and rail represent new technology. Yet, it does not much resemble the familiar S-curve. This is because, in the terminology of Chapter 5, the 'early adoption' phase is omitted and by 1910 adoption was still in the 'late majority' phase, not having reached the last 16 percent who comprise the

'laggards'. Thus, compared to the classic technology adoption curve, this curve is truncated at both ends.

Fig. 6.3.9 shows how affordability, literacy and access to the mail and rail networks have combined to produce a growth in epistlers and travelling epistlers. It suggests that literacy was the constraining factor up to about 1875 – being the lowest of the percentages – after which it was affordability.

Fig. 6.3.9: Model results: epistlers, affordability, literacy and access.



Because of the uncertainty regarding the growth of accessibility to the mail and rail networks, two alternative assumptions were tested:

- if there had been full access to the mail network initially, one third would have been epistlers rather than about a quarter as in the base case. (By 1910, it makes no difference as the base case assumes that all had access.)
- if access to the rail network had grown in line with urbanisation then by 1910 just over half would have been travelling epistlers compared to 7 out of 10 on the base case.

(Details in Table 6.3.3.)

Table 6.3.3: Model results: growth of epistlers and travelling epistlers by alternative access assumptions: 1840 and 1910.

Percentage of population	**1840**	**1910**
Epistlers		
Base case	23	72
Full access to mail network throughout	31	72
Travelling epistlers		
Base case	12	71
Rail access grows with urbanisation	14	56

Sensitivity analysis

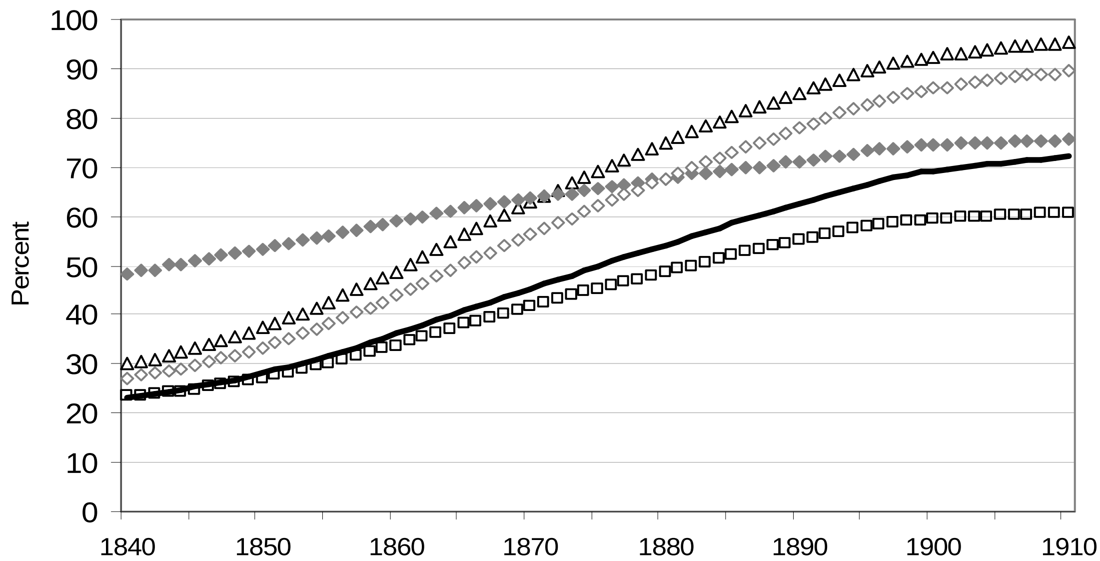
There is no information on the proportion of the population who were epistlers or travelling epistlers, so to test the model the effect of four unrealistic assumptions on the growth in these groups has been made.

- The Gini coefficient is set to about a third, as is observed today with the extensive tax-benefits system. The Gini coefficient was certainly higher in the nineteenth century, around a half as assumed in the base case.
- The affordability threshold is set to zero, meaning everyone could afford to use mail and rail services throughout the period although the historical evidence indicates that they were not. The base case assumes only those with half average incomes and above in 1840 could afford these services.
- No economic growth, although it is well established that there was significant economic growth: the base case assumes 1 percent a year.
- 100 percent literacy throughout, which is known not to be the case.

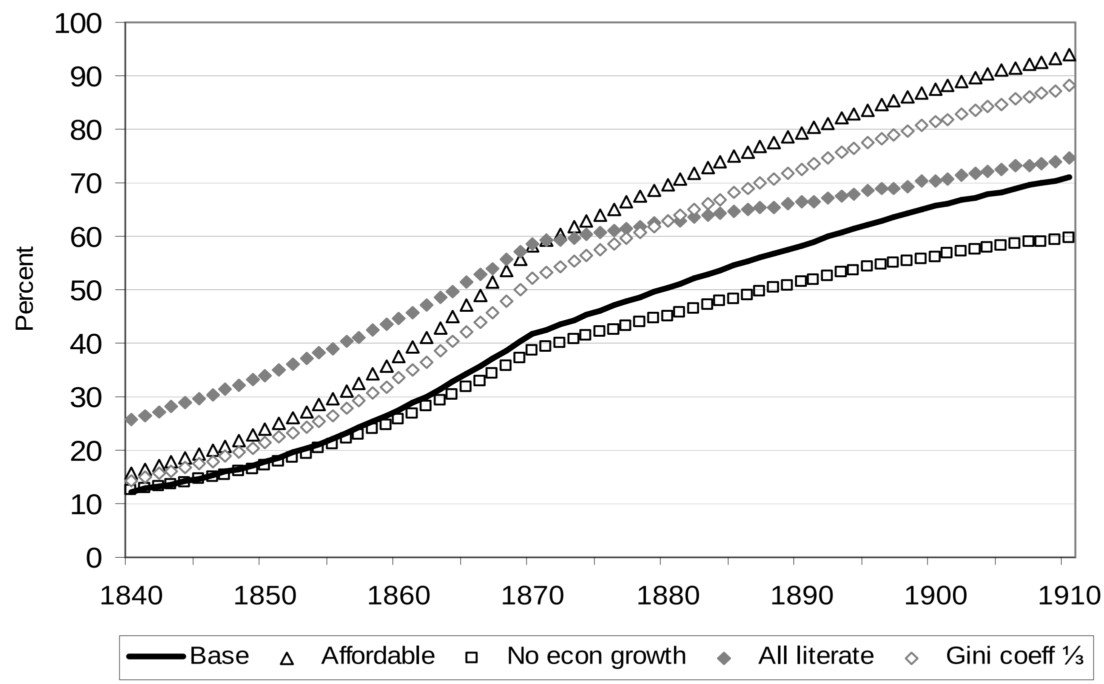
Fig. 6.3.10 shows how these totally unrealistic assumptions produce growth paths that bracket the base case (the thick dark line). It confirms that literacy was the constraining factor up to about 1875: for example, had everyone been literate in 1840, half the population would have been epistlers instead of a quarter. Later, it was affordability rather than literacy than was the constraint: had everyone been able to afford the services, some 90 percent would have been epistlers by 1910 instead of some 70 percent. But had there been no economic growth, only 60 percent would have been epistlers. This is perhaps surprising but is consistent with the income distribution shown in Table 6.3.5 which shows that 64 percent had an initial income above the threshold. A similar pattern emerges for the travelling epistlers.

Fig. 6.3.10: Model results: sensitivity analysis: percent of population of who are epistlers and travelling epistlers: 1840-1910.

Epistlers



Travelling epistlers



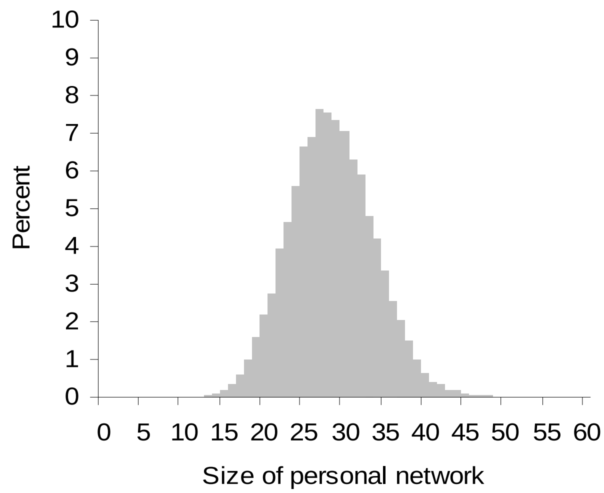
6.4 Model of Use

Section 6.3 looked at adoption but not at actual use in the sense of how many letters were sent or rail journeys undertaken. This Section looks at the factors underlying the observed growth in the use of mail and rail services. There is a real danger with modelling of this kind of assuming, often inadvertently, what one sets out to prove. It would clearly be erroneous to assume that *x* items of mail per head are sent a year or *y* journeys made. I have therefore made indirect assumptions and aimed to keep these assumptions to the minimum. Therefore this Section looks at what might have affected personal networks and thus the use of mail and rail services. It first looks at mobility and then at the cumulative effects of mobility and the change in the number of epistlers.

In Section 1 it was argued that British society was mobile before the introduction of the universal Penny Post and the railways but these two innovations transformed communications and travel.

Using the model described in Chapter 4, it is assumed that all agents start with a social reach of 30, which on average gives a personal network of about 28, distributed as shown in Fig. 6.4.1. This is consistent with the intentional personal network identified in Chapter 5.

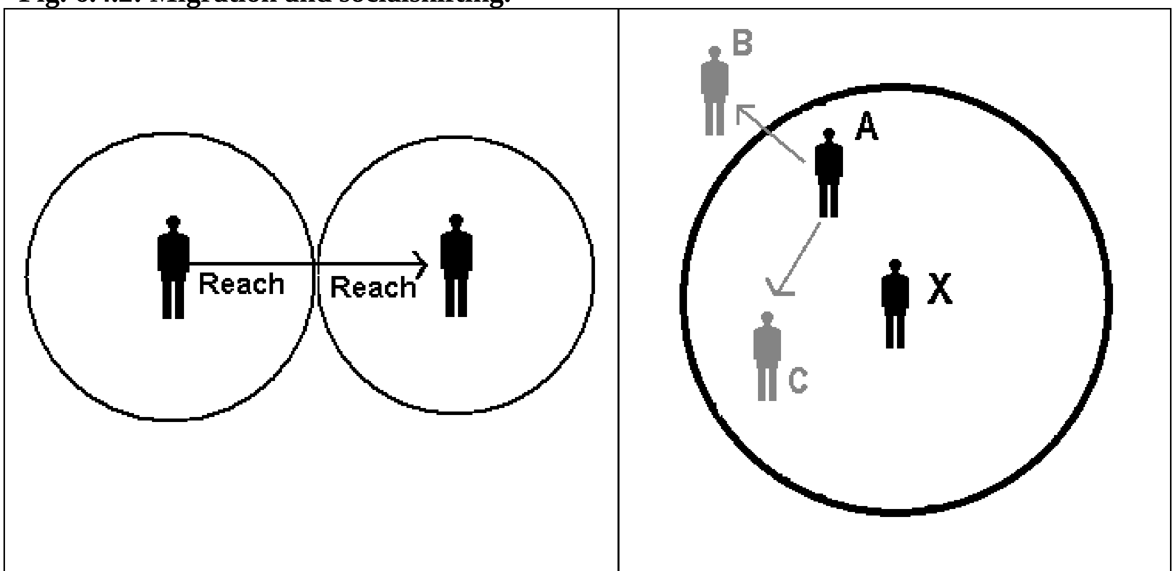
Fig. 6.4.1: Distribution of personal network size for social reach equals 30.



Two kinds of movement are modelled, illustrated in Fig. 6.4.2:

- migration that seriously disrupts personal networks: agents are assumed to move twice their social reach, and
- socialshifting (as discussed in Chapter 4) involving small steps, which may not disrupt their personal networks. Only if an agent 'shifts' outside another agent's social reach will the personal network be changed: for example, in Fig. 6.4.2, if A moves to C, X's personal network will not change but if A moves to B, it will.

Fig. 6.4.2: Migration and socialshifting.



Migration	Socialshifting

It is assumed that epistlers can maintain their links when they move. Thus as migrating agents move twice their social reach, they lose contact with their home personal network unless they are epistlers. Migrating epistlers maintain contact with other epistlers in their close personal network, which varies between agents but is assumed to have an average size of three. ('Close' is defined as before – see Box 6.3.5.) Think, for example, of a girl away in service: who would she write to? Her mother? Sisters? Boyfriend?

Most migrants were young: migration rates peaked around age 20 and then dropped steadily, flattened out and then started to rise again after age 60 (Schurer, 1991). For simplicity, it is assumed that 5 percent of under 25s migrate each year and to ensure that 80 percent of migrants were under 25, the migration rate for older agents was set at one tenth of that for the under 25s (i.e. ½ percent). Baines & Wood (2004) suggested that letters prompted migration and Thompson (1939/1973, p.162) and Horn (2003, pp.5-7) noted the importance of contact through those who already had places in obtaining jobs. So for epistlers, the migration rate is 50 percent higher (i.e. 7½ percent of the under 25s migrate).

It was shown in Chapter 4 that if just 5 percent shift one step each period, then over 10 periods, between a third of small personal networks and almost two-thirds of larger ones of will change. It is assumed here that each year 5 percent of agents socialshift. As with migration, epistlers are assumed to be 50 percent more likely to socialshift i.e. 7½ percent. It is assumed that epistlers maintain links when they socialshift but non-epistlers do not.

Links, whether created by migrating or shifting, are dissolved either by one party dying or by random destruction: it is assumed that 5 percent of links are broken randomly each year.

The pseudo-code is shown in Box 6.4.1.

Box 6.4.1: Mobility: pseudo-code.

Socialshifting
Number of agents to shift calculated based on rates of 7.5% for epistlers, 5% of others
Epistlers to shift create links with other epistlers within social reach of 30.
Number of shifts counted.

Migration
Number of agents to migrate calculated based on these rates:
- under 25s: 7.5% of epistlers, 5% of others
- 25 and over: 0.75% of epistlers, 0.5% of others

Epistlers create links with other epistlers with social reach of 10.
Migrating agents move 60 units (twice their social reach of 30)
Number of migrations counted

For each agent, distance from initial position measured.

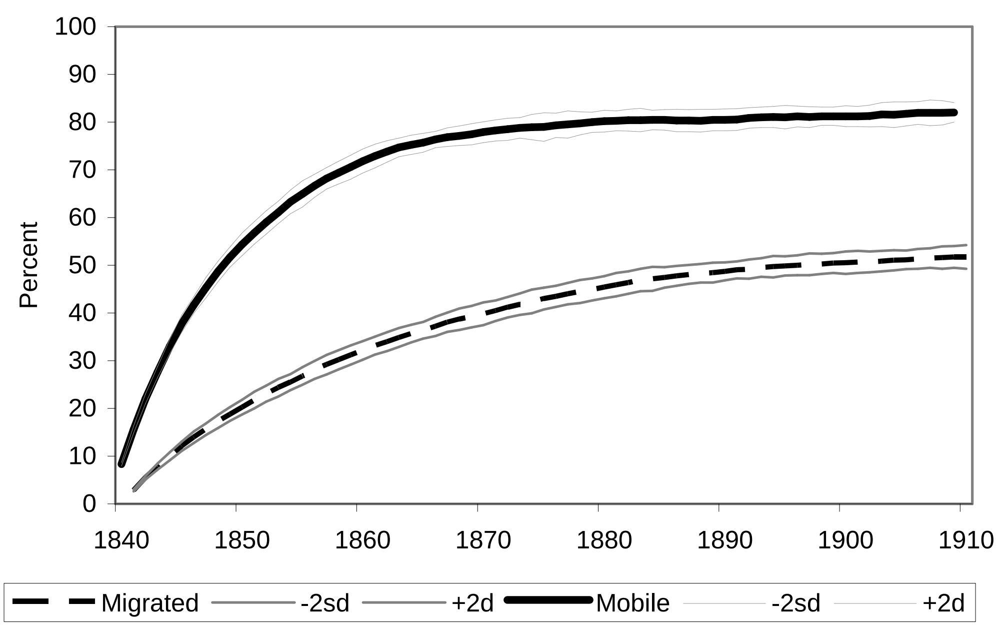
Migration raises an issue concerning the start up of the model and agents' history. Those who migrated before the introduction of the universal Penny Post and railways would have had difficulty keeping in touch. But the model makes no assumptions about the agents' history although it generates their history as it runs:

- all agents have a migration counter that is incremented each time the agent migrates and
- for all agents, their initial position is recorded, and the distance moved from that initial position, by migration or socialshifting, is calculated at each step.

As noted above, by the end of the 70 year period, on average 99 percent of the original agents have been replaced so their movement histories are in effect generated by the model.

On this basis, half the population migrates at some time while three-quarters are defined as 'mobile', moving as a result of socialshifting, migration or both. Of those who migrated, two thirds did so only once and a quarter migrated twice. (Details in Fig. 6.4.3.) This is consistent with studies based on linking Census records which suggest a turnover rate of about 50 percent over 10 years (Schurer, 1991).

Fig. 6.4.3: Model results: proportion of agents who are mobile.
(Mobile means moving as a result of socialshifting, migration or both.)



Before turning to the discussion of the results, Box 6.4.2 summarises the whole model.

Box 6.4.2: Summary of whole model.

Initialisation

Agents allocated ages and incomes. (See Boxes 6.3.1 and 6.3.3.)
Agents' access to mail and rail services determined. (See Box 6.3.2.)
Agents' ability to afford mail and rail services determined by comparing agents' income with the affordability threshold.
Literacy determined. (See Box 6.3.5.)
Personal networks measured.
Records initial co-ordinates.
Initial summary statistics recorded.

Execution

Agents age.
Incomes grow and agents' ability to afford the services is recalculated. (See Box 6.3.2.)
Links broken.
Mail and rail access spreads. (See Box 6.3.2.)
Literacy spreads by influence. (See Box 6.3.5.)

Agents die according to mortality rates. (See Box 6.3.1)
Replacement agents are created and distributed randomly, allocated income and their mail and rail access and literacy are determined. (See Boxes 6.3.1, 6.3.2, 6.3.3 and 6.3.5.)

Summary statistics about access, affluence and literacy recorded.

Agents move by socialshifting and migration, creating links as appropriate. (See Box 6.4.1.)

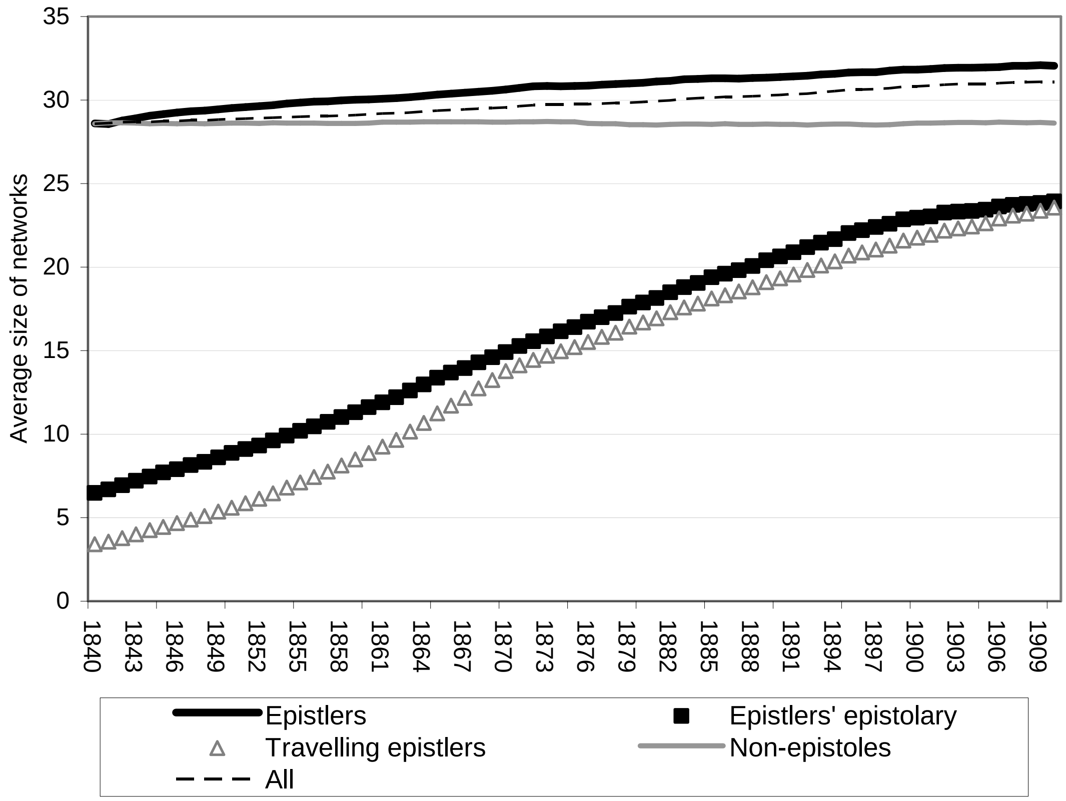
Personal networks measured, within circles and links beyond circles.

Summary growth statistics recorded and graphs plotted.

Results

The change in the size of personal networks is shown in Fig 6.4.4. Overall, the average personal network size increased by 9 percent. As expected, the average personal network size of the non-epistlers does not change. However, the average size of epistlers' personal networks rises from 28 to 32 – by 14 percent – as a result of their being able to keep in contact with those with whom they would otherwise have lost contact. More importantly, within the epistlers' personal networks, an increasing proportion of their links are to other epistlers – the epistlers' epistolary network – initially on average just 6½ of the 28 are also epistlers, rising to 24 out of 32 by the end of the period. For the travelling epistlers, the growth is even greater. Initially travelling epistlers have on average 3½ other travelling epistlers in their personal networks. By the end the average size of these travelling epistolary networks is 23½.

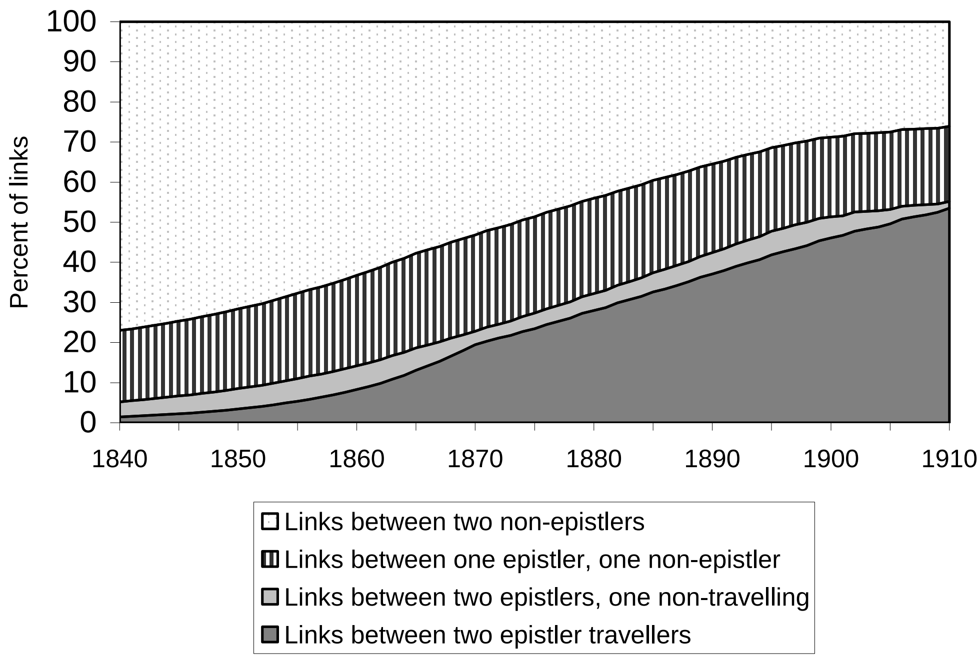
Fig. 6.4.4: Model results: change in size of personal networks.



Notes: Standard deviations: all, 0.2; epistlers' network: 0.3; epistlers' epistolary, 0.5; epistlers' travelling epistolary, 0.5; non-epistlers, 0.3.

As the proportion of epistlers rises, the proportion of epistlers in each agent's personal network also rises i.e. the epistolary network is growing. The number of links increases (approximately) by the square of the number of agents in the network (see Chapters 3 and 5). As shown in Fig. 6.4.3, in 1840, on average each agent has 28 links and so there are 28,000 directed links in the network. Almost a quarter of the agents are epistlers and on average they are linked to 6½ other epistlers. Thus about 1,500 links – or 5 percent of the total – are between epistlers. By 1910, the number of epistlers approximately trebles and the average number of epistlers in their networks rises to 24, giving some 17,000 links in total. However, the total number of links has increased to 31,000 (due to the increase in size of personal networks). Thus by 1910 epistolary links account for just over half of the total number of links; and most are between travelling epistlers. These results are illustrated in Fig. 6.4.5.

Fig. 6.4.5: Model result: epistlers' share of total links.



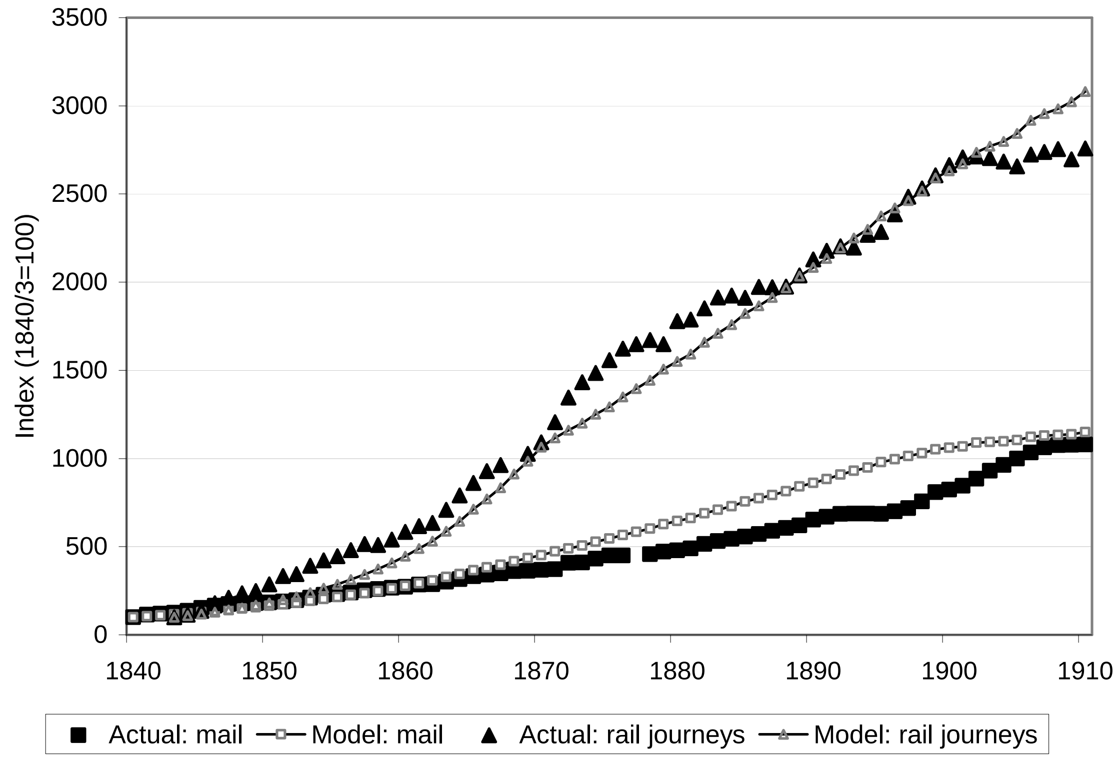
Thus, roughly, trebling of the number the epistlers has increased the number of epistolary links by elevenfold, from 1½ thousand to 17 thousand, broadly consistent with the almost tenfold rise seen in mail per head, given that not all the links will result in communication by mail. (Details in Fig. 6.4.6.)

To compare the growth in links between travelling epistlers, 1843 must be taken as the start year because that is the first year for which rail data is available. The model shows that only 13½ percent of the agents were travelling epistlers then and on average only 4 of their links were to travelling epistlers. Thus there are only some 500 travelling epistolary links. By 1910, the number of travelling epistlers increases over fivefold and the average number of travelling epistlers in their networks rises to 23½. This means that the number of epistolary links increases to about 16,500. Thus a fivefold increase in the number of travelling epistlers has increased the size of the epistolary network more than thirtyfold (16,500/500), consistent with the thirtyfold rise seen in rail journeys per head, given that not all the links will generate rail journeys. These results are shown in Fig 6.4.6.

The model was intended to gauge the potential for communication by mail and travel by rail. Not all the links created would “carry” mail or generate rail journeys. So the growth rates in the model are expected to be higher than actually occurred. And because much detail has been omitted, the model’s predictions are not expected to track year-by-year growth precisely. Nevertheless, the model does indicate how the observed growth rates might have been generated.

The adoption model was tested by examining the effect of unrealistic assumptions. This usage model was tested by assuming that there was no mobility, which is clearly unrealistic given the historical evidence. If there were no migration, there would be no overall increase in the sizes of personal networks, but the epistolary networks would nevertheless increase as the number of epistlers increased. However, the average number of epistlers in their networks would rise from about 6½ as before to 20. Thus the number of links initially would be about 1½ thousand as before but by the end would be nearly 15,000 giving a tenfold increase. For travelling epistlers, the rise would be about twenty-fivefold: from around 500 to just over 14,000. Thus the growth in the networks would have been substantial even if there had been no migration. (Details in bottom panel of Fig. 6.4.6.)

Fig. 6.4.6: Model results: actual mail and rail journeys per head compared to model.



Note: Mail: 1840 = 100. Rail: 1843 = 100, with model taken from1843.

Model based on increased sizes of epistolary and travelling epistolary networks.

	% agents	Av no. in networks	Links
Epistoles			
1840	23%	6½	1,495
1910	72%	24	17,280
Increase	3.1	3.7	11.5
Travelling epistoles			
1840	13½%	4	540
1910	71%	23½	16,685
Increase	5.3	5.9	30.9
No mobility: 1910			
Epistoles	72%	20	14,440
Travelling epistoles	71%	20	14,420

6.5 Discussion and Conclusion

The model described in this Chapter has taken the availability of the mail and rail networks as exogenous but has attempted to model their use, drawing on the general model set out in Chapter 5, which is in turn based on the idea that communications networks grow out of social networks. It has looked at the potential for communication and travel by assessing the impact of mail services on personal networks. The target was to explain the growth in the number of letters per person from 8 in 1840 to 75 in 1913; and the growth in the number of rail journeys per head per annum from 1 in 1843 to 35 in 1913. Evidence suggests that personal rather than business use was an important factor in the growth of both. Table 6.5.1 summarises the model.

Table 6.5.1: Summary of the model.

Target	Use of mail and rail services: 1840-1913	
Agents	Individuals	
Agents		
	Attributes	Dynamics
Location	Random	
Demographic	Age	Birth and death
Socio-economic	Income	Income growth
Skills	Literacy	Young agents replace less literate old; and influence of close personal network
Personal networks:		Socialshifting & migration
- close	Social reach = 10	
- intentional	Social reach = 30	

It is a simple model and has not taken into account detailed changes. For example:

- Agents have not been divided by gender although there were differences in age-specific mortality rates and literacy rates.
- Agents have not been divided by class, although differences in income have been included.
- It does not take into account the business cycles that were characteristic of the nineteenth century British economy.
- It does not take into account the changes to the mail system made in the 1870s.
- It has assumed one affordability threshold although a case could be made for having a higher threshold for rail than for mail.

The model suggests that the increase in the number of links matched the increase in the use of mail and rail services. It was not surprising to find that affordability – the rise in real income – was an important factor in the rising use of mail and rail services. But the role of literacy was brought out by the model.

Returning to the four communications effects identified in Chapter 5:

- **Social solidarity.** This is the idea that a new communication mode will be used to send messages to those in agents' existing personal network. This accounted for most of the mail sent.
- **Communication substitution.** There was no substitution because there were no substitutes available. When the universal Penny Post was introduced, travelling to meet face-to-face was the only alternative to sending a letter.
- **New practices** developed, especially the sending of cards.
- **The global village effect.** The universal Penny Post made it possible to maintain contacts that would otherwise have been lost. The model suggests that this effect might have increased personal networks averaging 28 by 9 percent on average; by 15 percent for epistlers i.e. by 3 to 4.

At the same time as communications were transformed by the universal Penny Post, transport was transformed by the railways. Considering the three travel effects identified in Chapter 5:

- **Complementary travel**

  Long-distance travel became accessible to far more people than previously: from an estimated 0.6 journeys per head a year by coach in 1835, there were 35 per head per year by rail in 1913. People were able to keep in contact and this is likely to have encouraged travel. Indeed, letters from migrants encouraged others to migrate.
- **Travel communications**

  The growing number who could use the mail services and travel suggests that there was likely to have been more communication about travel, especially using cards.
- **Travel substitution** There is no evidence that mail substituted for travel.

Table 6.5.2 summarises the results.

Table 6.5.2: Summary of the results.

Target	Use of mail and rail services: 1840-1913	
Adoption		
Key factors	Literacy to 1875 Income growth from 1875 Access to mail & rail	
Use		
Communication effects Social solidarity? Communication substitution? New practices 'Global village': - maintain contact? - new friends?	 Yes No Yes Yes No	 No substitutes available Cards Personal networks increased by 9%
Travel effects - Complementary increase? - Travel communications? - Substitution reduction?	 Yes Yes No	 No evidence.

To sum up: British society was mobile before the arrival of the universal Penny Post and the railways. There was, arguably, a pent-up demand waiting to be met. The mail and rail innovations permitted communication and travel on a previously unprecedented scale. The rise in the use of mail and rail per head far outstripped growth in GDP per head, primarily due to the growth in literacy and the development of new practices.

What the modelling has shown is that it is possible to bring together a set of evidence-based assumptions that, when combined, show how the observed dramatic growth in use of mail and rail services might have come about. It also indicates the relative importance of different factors identified by history and theory. The model distinguishes the global village effect from increased contact with the pre-existing personal network and suggests that the latter far outweighs the former. It also shows how the growth in communications was driven by increasing literacy, and was at first facilitated and later constrained by economic factors. Perhaps most importantly, it underlines how the demand for both mail and rail could be generated by personal networks: which may in turn help to explain why they are complements rather than substitutes.

Chapter 7: Phones and Cars

This Chapter presents a case study of the adoption and use of phones and cars by households in the second half of the twentieth century, once again based on the social circle model described in Chapter 4. While there are some features common to this model and that presented in Chapter 6, this model differs in many important respects reflecting the differences between the technologies, the social and economic conditions and the availability of data.

Phones and internal combustion engines first appeared in the same year, 1876 (Huurdeman, 2003, p.89). Phones were available from the late 1870s and cars started to appear on British roads in the 1890s. But the spread of both was disrupted by two World Wars which caused shortages that distorted consumers' behaviour. Thus this case study starts in 1951 when life was starting to return to normal after the Second World War. Data on household phone and car ownership became available together with background information from the 1951 Census (General Register Office (GRO), 1952). The case study covers the following 50 years in order to benefit from the 2001 Census data. However, the model is not expected to perform well towards the end of the period because the digital revolution started to have an impact: the percentage of households with phones peaked at 95 percent in 1999, after which it started to drop as mobiles were substituted (ONS, 2008a). The digital revolution is discussed in Chapter 8.

There does not appear to be any study of the diffusion of the telephone in Britain similar to that undertaken by Fischer in *America Calling: A Social History of the Telephone to 1940*. Although conditions and timing in Britain were different, this case study draws on clues suggested by Fischer's analysis. Fischer (1992, p.58) suggested that the histories of phones and cars in the United States have "noteworthy similarities and differences". They were similar in that:

- "both emerged from 'parent' technologies, the telegraph and the bicycle respectively and that inheritance shaped their early histories"
- "both started out as expensive devices favored by the well-off".

But there were differences too, he argued: "the telephone was initially a business tool leased from a single provider, while the automobile was a toy bought from a variety of producers". Fischer (ibid) suggested that cars were adopted faster than phones, despite their higher costs, because cars were supplied by a competitive industry and were subsided by government-funded roads, while phones were supplied by monopolies.

Data

In addition to drawing on Fischer's work, Halsey and Webb's (2000) *Twentieth-century British Social Trends* is also used extensively. Demographic statistics are from the decennial Censuses. For the first part of the period the two key sources of economic statistics are the same as for Chapter 6: Mitchell (1988) and Feinstein (1972). Data for later years is available from the Central Statistical Office (CSO) and its successor, the Office for National Statistics (ONS). The Chapter draws in particular on surveys of family expenditure that were carried out from 1953/4 by the Ministry of Labour, then by the Department of Employment (DE), CSO and currently, ONS. These surveys also provide data on the household adoption of phones. Other data on phones is available first from the Post Office, followed by BT plc and its regulators, Office of Telecommunications (Oftel), and then Office of Communications (Ofcom). Data on cars is available from various Government sources, especially, the Department of (then 'for') Transport (DTp then DfT).

Outline of the Chapter

The Chapter starts by setting the scene, describing the growth in phone and car use in Britain during the twentieth century in Section 1. Sections 2 to 5 describe the modelling. In this model, the agents are households rather than individuals as in Chapter 6; so Section 2 explains how the formation of households was modelled. Section 3 then describes how the households were divided by class and allocated income, the method used for income allocation being different from that used in Chapter 6. Section 4 then presents the model of adoption, drawing on the previous two Sections. Section 5 presents the results. Section 6 briefly discusses, but does not model, usage and Section 7 concludes.

7.1 History

This Section looks first at the history of phone adoption, then at cars and concludes with a set of stylised facts to be explained by the model.

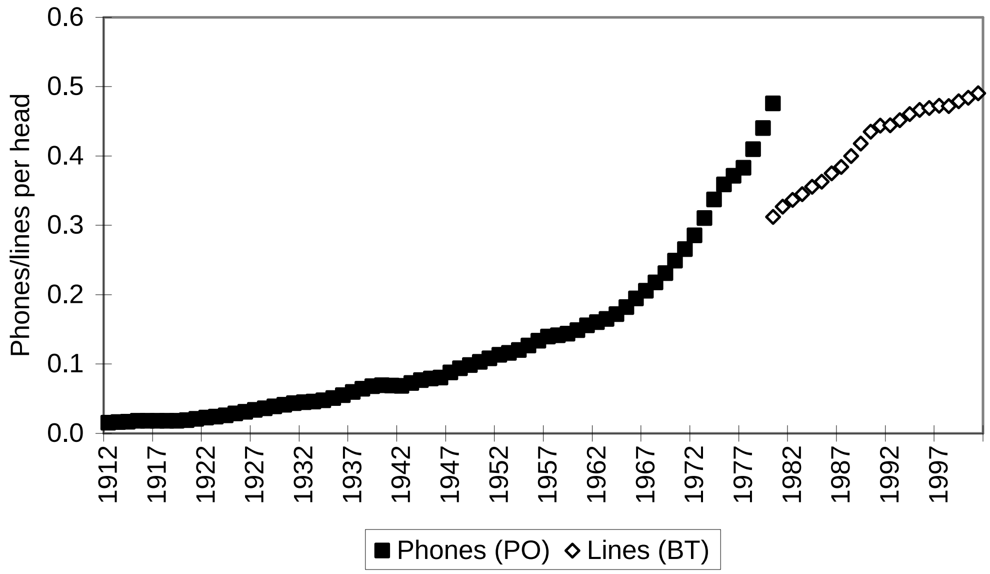
Phones

Initially, phone subscribers had private lines (Casson, 1910/2007, p.86) but the first British phone directory was issued in 1880 and "contained details of over 250 subscribers" plus details of 16 provincial exchanges: almost all of these subscribers were businesses (The Telephone Company, 1880; Hamill, 2010). By 1882, there was one phone for every 3,000 people in London: by 1890, the ratio was one per 800 but it reached one per 100 in 1905 (Perry, 1977). Adoption was slow due to price and poor regulation of the nascent phone industry (Perry, 1977). By 1910-12, there were some 600 thousand phones and a quarter to a third of these were in London (Casson, 1910/2007, p.87; Huurdeman, 2003, pp.230 & 235; Perry, 1977).

Initially there were many, often competing, phone companies. But with the exception of the Kingston-upon-Hull phone company, the phone industry was nationalised in 1912 and put under the control of the Post Office. It became a separate nationalised industry, British Telecommunications in 1981; and in 1984 British Telecommunications was privatised, becoming BT plc (BT Archives, 2009). At first it was regulated by Oftel, which was subsumed into Ofcom in 2002 (Ofcom, 2009c).

From 1912 the number of phones – either business or residential – grew at a rate of almost 5 percent a year so that by 1984, there was one phone for every two people. That data series was discontinued when BT was privatised in 1984 and replaced by the number of phone lines, at which time there was one for every three people. This grew at around 2 percent a year to 2001, when there was one phone line for two people. Fig 7.1.1 shows this data in terms of phones per person. (For example one phone for every two people becomes 0.5 of a phone each.)

Fig. 7.1.1: Phones (business and residential) per head: UK: 1912-2001.



Sources: Phones ("stations"): Mitchell (1988). Lines, BT (2009a) Population: Mitchell (1988), ONS (2009b, series DYAY).

Data on household adoption of phones is available from 1951, albeit ad hoc in the 1950s but from the mid-1960s, annually from surveys. In 1951, just 10 percent of households had phones; by the mid-1970s, half had phones. The proportion peaked in 1999 with 95 percent of households with phones (Details in Fig. 7.1.3.)

Public phones were available from 1884 (Connected Earth, 2009b). In 2009, BT still operated some 63 thousand public payphones (BT, 2009b). However, while at first public payphones were seen as a way of making people more aware of telephones, between the Wars, they provided "an easier way to extend services to remote or rural areas" and "after 1945, the telephone box was sometimes the only way of providing services to the housing estates and new towns that were springing up all over the country" (Connected Earth, 2009). While undoubtedly important to many communities, payphones are not discussed further here.

Data on the number of calls is available only up to the privatisation of BT in 1984 (Root, 2000, p.444). This data covers business as well as residential calls and no split is available. From 1992/3, data is available on the number of minutes called. But as there is no overlap between the two series and there is no information on the average call duration, it is not possible to splice the two series.

Cars

The adoption of cars can be divided into three phases; before the First World War, the interwar period, and post-1950 (O'Connell, 2007, p.113).

- The first petrol driven road vehicle was produced in Germany by Benz in 1878, and by 1896, cars were being produced in Britain (Dyos & Aldcroft, 1971, p.334). Cars were luxuries. (O'Connell, 2007 p.113). By 1904 there were 8 thousand cars in Britain (Mitchell, 1988) and by 1914 "1 person in every 232 in Great Britain owned a car" (Root, 2000, p.445). The first social use of the car is reported to have been by Mrs Benz in 1885 (Urry, 2007, p.113).
- By 1922 "car ownership had become much more commonplace amongst middle- and upper-class men" (Root, 2000, p.445). In 1938, when about 20 percent of families had cars, "even the cheapest models were still beyond the reach of most households" (Scott, 2007, p.171) and were largely confined to the middle class (Root, 2000, p.445; O'Connell, 2007, p.207). In 1930s and 1940s, car use was for pleasure not commuting (Pooley et al, 2005, pp.128-130).
- Post-1950 marked the mass-market stage (O'Connell, 2007, p.113) although cars "remained a luxury until the 1960s, when mass production and the resulting lower prices made buying, selling (and often maintaining and upgrading) cars an option, for the first time, for the majority of households" (Root, 2000, pp.448-9). During the 1950s and 1960s, cars were still used primarily for leisure. Only with the arrival of the company car was it seen as acceptable to use it for travelling to work (Pooley et al, 2005, pp.128-130). By 1998/2000, 8 percent of cars were company cars (DfT, 2006a, Table 9.17).

While this case study focuses on cars, other forms of motorised transport were important before cars came to dominate. Buses were important before and immediately after the Second World War (O'Connell, 2007, p.113; DTp, 1979, p.15). At the start of the second half of the twentieth century, motorcycles were popular too: in 1950, there was one motorcycle for every 3 cars but by 2000 this had fallen to one for every 28 cars (DfT, 2006a, Table 9.1).

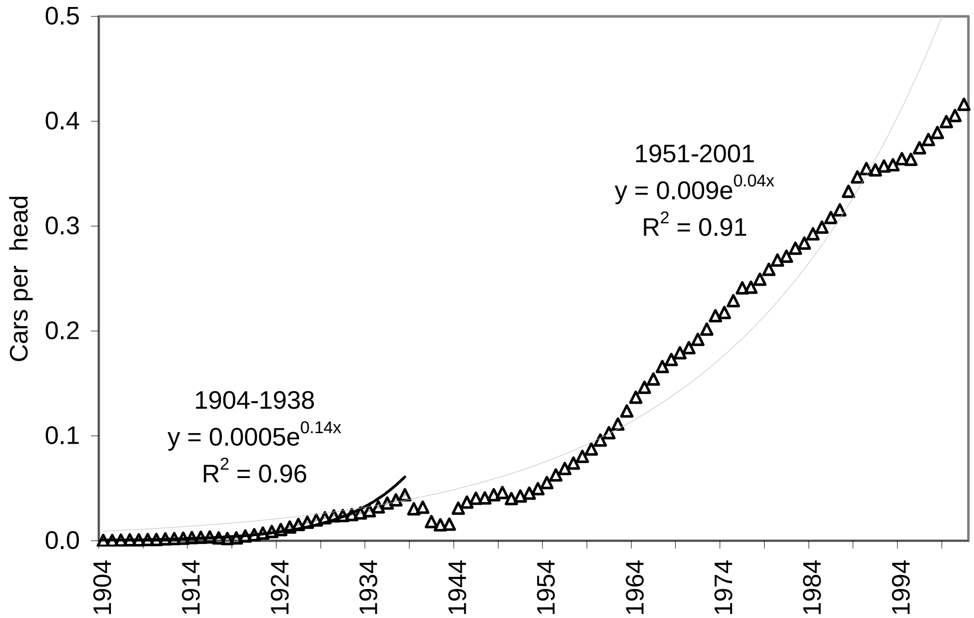
In 1904 there was just one car per 5,000 people. From 1904 to 1938, the last full year before Second World War, cars per capita grew on average by about 14 percent a year. By 1951, there was one car for every 25 people. Cars per head grew at about 4 percent a year so that by 2001, there was one car for every 2½ people. Fig. 7.1.2 shows the inverse of these numbers i.e. the number of cars per head.

Data on households with cars is available from 1951 when just 14 percent had cars. By the early 1970s, half of households had cars; and by 2001, three-quarters. (Details in Fig. 7.1.3.) Furthermore, since the early 1970s the proportion of households with more than one car has risen from 10 percent to about a quarter by 2001 (DfT, 2008, Table 9.14).

Part of this increase in the proportion of households with cars can be explained by the increase in women and older people driving.

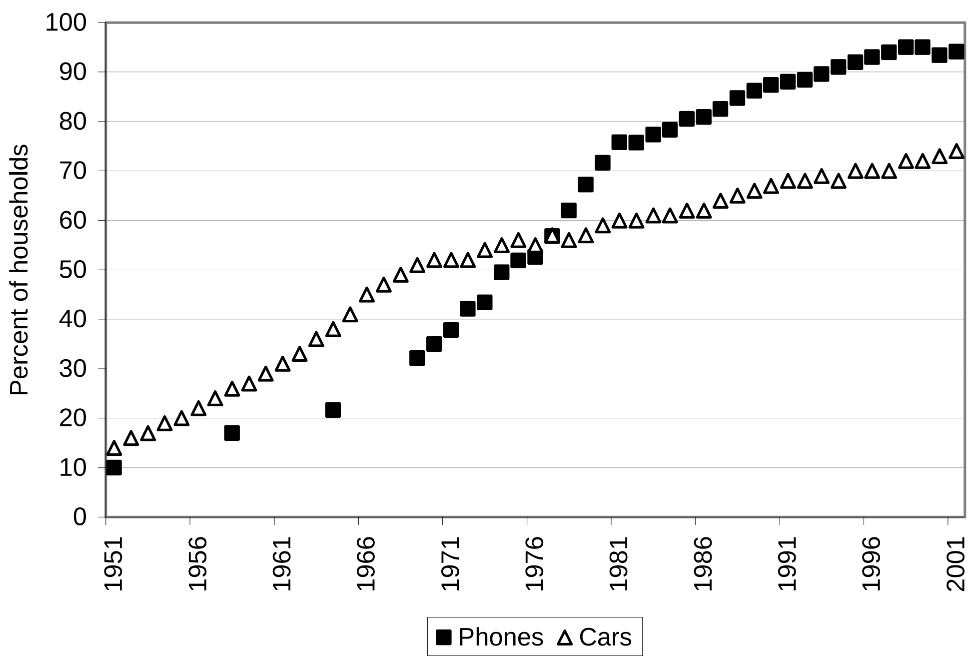
- Cars were initially seen as being for men, and women were discouraged from driving (O'Connell, 2007, pp.117-119). Thus by 1965, 50 percent of men had driving licences but only 10 percent of women. By 1999, 60 percent of women had licences. This was not simply a generation effect, with younger women being more likely to drive than older women. In 1965, for example, 15 percent of women aged 21 to 29 had driving licences: ten years later, 48 percent of the same cohort, then in their 30s, had licences (DTp, 1979, Table 2.1; DfT, 2006a, Table 9.16). This is likely to have contributed to the growth of multi-car households.
- In 1965, only 9 percent of those aged 65 and over had licences (DTp, 1979). By 1999, 39 percent of those aged 70 and over had licences (DfT, 2008, Table 9.16). This does appear to be a generation effect: rather than older people passing their driving tests, people who already had licences were ageing and were more able to afford to keep a car.

Fig. 7.1.2: Cars per head: GB: 1904-2001.



Sources: Mitchell (1988), DfT (2007b), ONS (2007b).

Fig. 7.1.3: Percentage of households with phones and cars: GB: 1951-2001.



Sources:
Phones: 1951: 1.5 million households had phones (Marwick, 1990, p.117) and there were nearly 15 million households (see Table 7.3.4) 1958: Douglas & Isherwood (1979, p.99)
1964-1993: CSO (1994, Table 9.3) 1994 on: ONS (2008a, Table A50)
Cars DfT (2008, Table 9.14)

Data on journeys has been collected since the mid-1960s (DTp, 1979; Pooley et al, 2005, pp,36-7). "Visiting friends" accounted for 14.3 percent of trips by all transport modes in Britain in 1965 and 17.6 percent in 1999/2001; work, and increasingly, shopping, are the main reasons for trips (Pooley et al, 2005, p.59). In other words about 85 percent of travel is not for social reasons: and most trips to work, shop and visit friends are by car (DfT, 2006).

Stylised facts

Although household phones appear to be used primarily for social reasons (for example, Fischer, 1992, p.225), the same cannot be said for cars, as just noted. There is continuous data on phone calls only up to 1984 and data on journeys only from 1965. There is, however, data on the adoption of both phones and cars from 1951. Unlike the last Chapter when there was little data on adoption, but a great deal on use, in this case, there is data on adoption but relatively little on use. The modelling therefore focuses on adoption by households.

As shown in Fig. 7.1.3, the spread of phones follows the classic S-curve but that of cars does not. Until 1977, cars were more popular than phones. There are therefore two key facts to be explained: between 1951 and 2001:

- the percentage of households with phones increased from 10 percent to 94 percent;
- the percentage of households with cars increased from 14 percent to 74 percent.

7.2 Modelling Households

To reflect the fact that phones and cars are resources available to households and that it is household income that is important (Brynin et al, 2007, p.4), in this model the agents represent households rather than individuals. A household is a set of people living at a single address: the individuals comprising the household may or may not be related. For example, the 2001-02 *Family Spending Survey* (ONS, 2003, p.141) defined a household as

> "one person or a group of people who have the accommodation as their only or main residence and (for a group) share living accommodation, that is a living room or sitting room or share means together or have common housekeeping … members of a household are not necessarily related by blood or marriage".

The creation and dissolution of households is complicated – see, for example Coleman & Salt (1992, p.219) and Haskey (2001) on cohabitation. For example, death may not mean the household 'dies' if the widow continues to live alone. Thus mortality rates of households are not the same as mortality rates of people. Households only 'die' when all their members die or disperse to other households or institutions. However, the purpose of this model is not to understand the household formation process, and therefore the demographic subprogram is a reduced form, using the minimum number of assumptions to reproduce key features of the demographic changes that have occurred since 1951, shown in Table 7.2.1.

Table 7.2.1: Key characteristics of households: 1951-2001.

		Age (1)				1 person households
		Under 40	40-59	60+	All	
1951	%	26	44	30	100	11
	% married	92	81	49	74	
	Mil (GB)				14.5	
2001	%	30	37	33	100	30
	% married (2)	55	67	46	56	
	Mil (GB)				24	

(1) In 2001, age of household reference person, a concept based on responsibility for accommodation, income and age, that has replaced 'head of household which tended to be defined as the oldest male. (See ONS, 2009d, pp.186-7.)
(2) Including cohabiting.

Sources: GRO (1952); ONS (2009d).

Table 7.2.1 shows that the number of households increased from 14½ million in 1951 to 24 million in 2001. However, for the same reasons as discussed in Chapter 6 the number of agents will be kept constant. Keeping the total number of households constant means that, in effect, the agents resemble a longitudinal sample. This means that when households combine, they do not combine within the sample as this would reduce the total: instead a partner is assumed to come from outside. Conversely, when a household splits due to divorce, one partner in effect leaves the model to prevent the number rising.

The main change to be modelled is the trebling of the proportion of single person households. This growth has mostly occurred since the 1960s and is due to young people leaving home and the increase in the number of elderly people (Coleman, 2000, p.78). This has resulted in a more even age distribution of households and a fall in the proportion of households comprising married or cohabiting couples, which has largely occurred since the 1980s. Thus the target of the demographic part of the model is to reproduce:

- the proportion of one-person households rising from 11 percent to 30 percent by 2001, half of which are pensioner households and
- the proportion of households aged 40 to 59 declines from 44 percent to 37 percent, while the percentages aged under 40 and 60 plus increase.

There are two types of households in the model: one-person and multi-person. And householders are either single or a couple. A single person can live in a multi-person household e.g. a lone parent with dependent children.

- Age. The earliest detailed age distribution of household heads dates from 1971 and shows that 5 percent of heads of households were under 25 and 1 percent 85 or over (DE, 1972). According to the 2001 Census, only 3 percent of household reference persons (HRPs) – a concept based on responsibility for accommodation, income and age, that has replaced ‘head of household’ (see ONS, 2009d, pp.186-7) – were aged under 25 and only 3 percent were over 85. The low proportion of very elderly is due to the fact that they are likely to live with others or in institutions: for instance, in 1981 one in five were living in institutions (Office for

Population, Census and Surveys (OPCS), 1984). The model assumes that no heads of households are aged under 25 or initially, 75 or over, although this maximum rises to 85 to reflect increasing longevity.

- Mortality. In the second half of the twentieth century, death rates for young adults were very low (Fitzpatrick & Chandola, 2000, p.98) so it is assumed that there are no deaths among those aged under 40. For those aged 40 and over, the rates fell for both men and women. (Details in Box 7.2.1.)
- Household size. In 1951, 8 percent of heads of households headed by someone under 40 were not married couples (Table 7.2.1). By 2001 67 percent of households headed by someone under 25 were headed by a single person (ONS, 2009d). Thus a rising proportion are assumed to be single, reaching two-thirds by the end of the period. Each year a certain percentage of single householders aged under 40 are assumed to marry or cohabit. Two person households are assumed to persist until the couple separates or one partner dies. Because the total number of households is fixed, when a single person marries or a couple splits, the household status is changed but there is no change in the number of households.
- Divorce and separation. The model does not distinguish between married and cohabiting couples and the same rates of 'splitting' are applied. Divorce was rare at the start of the period but rose sharply after the change in the law in 1971 (ONS 2007c, p.13). Divorce was most common in the under 40s and rare among those 60 and over (ONS, 2008b). On divorce, the marital status of the head of household is set to single and some become one-person households while others remain multi-person households (to reflect that fact that there are children in the household).

Detailed assumptions are in Box 7.2.1 with the pseudo-code in Box 7.2.2.

Box 7.2.1: Demographic assumptions.

Age and household type: initial assumptions

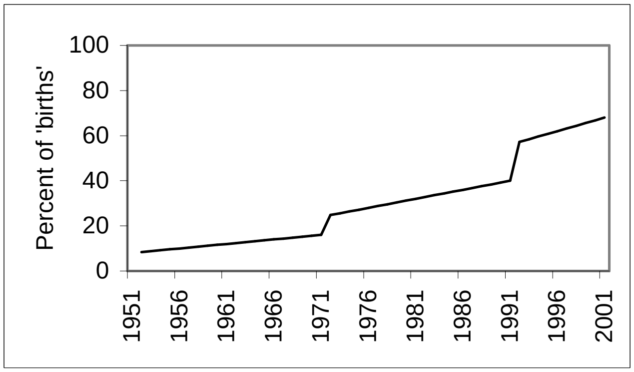
Household type	**Age of head**			
	25 to 39	40 to 59	60 and over	**Total**
One-person households	1%	3%	7%	**11%**
Multi-person households				
Married couple	24%	36%	15%	**75%**
Other	1%	5%	8%	**14%**
Total	**26%**	**45%**	**30%**	**100%**

'Births' and 'Deaths'

As the number of households is fixed, the number of 'births' equals the number of 'deaths'. Births are aged 25.

The proportion of 'births' that are single householders rises over time as shown on the right.

Half the new single householders are one-person households, half multi-person.



Mortality is assumed to be:

	Age			
	Under 40	40 to 59	60 - 70	Over 70
To 1961	0%	0.5%	1.0%	20%
1961 - 1971	0%	0.5%	1.0%	10%
From 1971	0%	0.5%	0.9%	8%

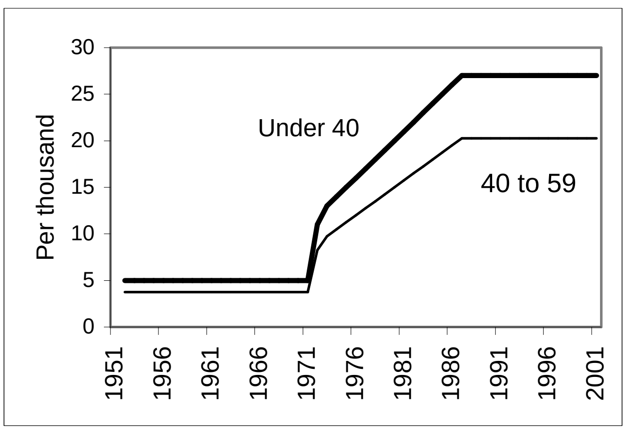
No household is 85 or over.

Marriage, divorce and widowhood

10% of one person households aged under 40 become multi-person households each year; 2.5% of those aged 40 to 59.

Couples under 60 divorce at the rates shown on the right. On divorce, two-thirds of the households revert to one-person households; one-third remain multi-person households. Both types become "single" and are eligible to remarry.

3% of households comprising couples aged 60 and over become widow(er)s each year: half that rate is applied to households aged 40 to 59.



Box 7.2.2: Demographic pseudo-code.

Initialisation

Create 1,000 multi-person households and distribute them randomly across a space to give a density of almost 1%.

Allocate ages

> Divide population into 3 broad age groups and then divide each age group into narrow bands of roughly equal size. Allocate age up to 75 randomly within groups.

Allocate marital status, then divide singles between one person households and multi-person households.

Execution

Existing households changed.

> Households age.
> Mortality rates applied.
> Widow rates applied to those 40 and over and widowed households become one person households.
> Some single households under 60 combine into multi-person households.
> Divorce rates applied to under 60s: divorcing households split between one-person and multi-person households.

New households created

> Population counted and new households created to bring the total back to 1,000.
> New households are distributed randomly and aged 25.
> A proportion of new households become single and some of these singles become one person households.

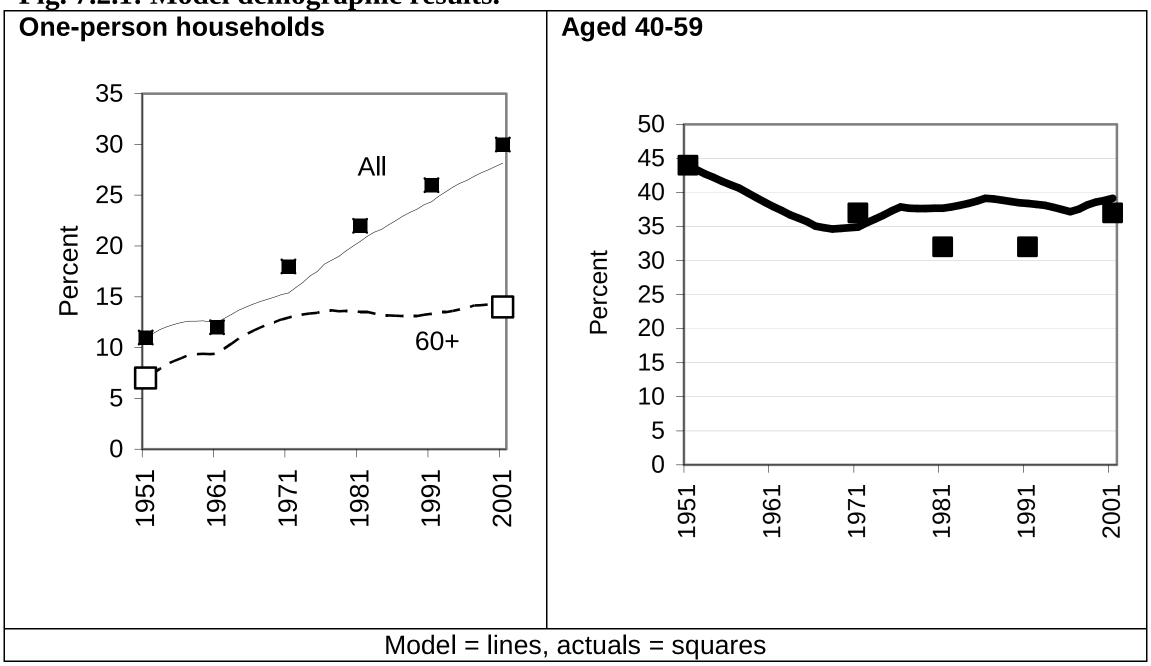
Various summary measures collected.

This model broadly reproduces the key demographic changes targeted.

- The proportion of one-person households rises from 11 percent in 1951 to 28 percent in 2001 (target, 30 percent), half of whom are aged 60 and over (target, half pensioner households) as shown in the left panel of Fig 7.2.1.
- The proportion of households aged 40 to 59 declines from 44 percent to 39 percent in 2001 (target, 37 percent) as shown in the right panel of Fig 7.2.1.

Only 6 percent of the original households survived to the end of the 50 years.

Fig. 7.2.1: Model demographic results.



Sources: GRO (1952); ONS (2009d); DE (1972 & 1982); CSO (1992).
Actual age data: definitions vary:

1971: based on age of Chief Economic Supporter;
1981: data based on 45-59/64 Coleman (2000, p.77).

7.3 Modelling Class and Income

Class and income and were important determinants of the adoption of both phones and cars. This Section presents the evidence and then describes how they are incorporated in the model.

Modelling Class

Fischer (1992, p.148) noted that in the early years of phone adoption in the US, two key factors were: “economic position, as indicated largely by head’s occupation and the presence of servants; and household structure”. In Britain, the nobility were early adopters of the phone: for example, Queen Victoria in 1878 (Casson, 1910/2007, p.86). Just before the Second World War broke out, only the richest households, *Mass Observations*’ ‘Class A’ – typically factory and shop owners and upper-grade civil servants – had phones, along with a medium-priced car; ‘Class B’ – younger professionals, “middle-aged and older bank and insurance officials and key workers in certain trades” – had a cheap or secondhand car and no phone; and below that, neither phones nor cars were to be found (Harrison & Madge, 1939/1986, pp.222-223).

Although by 1958 nearly 17 percent, of households had phones, phone adoption was limited to the “upper class” ABs and “middle class” C1s; two-thirds of the ABs had phones but phones were rare among the “lower class” C2s, Ds and Es. (Details in Table 7.3.1.)

Table 7.3.1: Phone adoption by class: 1958 and 1973.

Class	1958	1973
Upper: A, B	67.8%	88%
Middle: C1	25.3%	67%
Lower		
C2	}	44%
D, E	} 5.0%	20%
All	16.5%	45%

Source: Douglas and Isherwood (1979, p.100)

In 1953/4, the budget share of expenditure on communications – “postage, telephone and telegraph” – did not vary much by income, but it did vary by class: for middle and upper class households, it was about 1 percent; for manual households, ½ percent irrespective of income (Table7.3.2). This difference might have been due to the adoption of phones by the middle and upper classes.

Table 7.3.2: Percent of budget spent on communications by income and occupation: UK: 1953/4.

Status of head of household	Gross weekly household income: Under £8	£8-9	£10-13	£14-19	£20+	All	Average budget £ pw	% house-holds
Upper (1)	*	*	0.8	0.8	0.9	0.9	19	8
Middle (2)	0.9	0.8	0.8	0.8	1.1	0.9	14	10
Manual (3)	0.5	0.4	0.4	0.4	0.4	0.4	12	54
Own account	0.6	0.8	0.8	0.9	0.8	0.8	14	6
Retired etc	0.9	0.9	0.9	0.9	1.0	0.9	8	20
All	0.7	0.5	0.6	0.6	0.7	na	12	100

1. Employer/managerial
2. Professional, teaching, clerical
3. Incl. shop assistants
* Less than 100 in cell

Source: Ministry of Labour (1957, Tables 8, 25-29)
To convert to 2008 prices, multiply by 20 (ONS, 2009, series CDKO)

Douglas & Isherwood (1979, pp.192-4) and Bowden & Offer (1994) argued that the fixed line phone was adopted as a time-saving device: and Douglas & Isherwood went on to suggest that its adoption by the ‘lower’ classes was slow because “the poor have always had time on their hands with less things to do with it than the rich”. Not only did the class difference persist into the 1970s (Table 7.3.1) but even by the end of the twentieth century the upper classes still used phones more than the lower classes (Table 7.3.3). It also showed that some 10 percent of households did not have phones. Dyer (1997) suggested that these “unphoned” households tended to have lower incomes and be in inner city locations.

Table 7.3.3: Oftel’s 1995 analysis of residential customers’ groups.

	Estimated no. (mil)	Telecoms spend per quarter	Age	Social classes	Other
Incomes over £7,500 pa					
“High spenders”	4	Over £70	30 - 50	A to C2	Full time employment
“Medium Spenders”	8½ to 9½	£35 to £70	20 - 40	C2 and C1	In employment
“Low spenders by choice”	2½ to 3½	£35 or less		C2 and C1	⅔ in employment 1/5 retired
Incomes less than £7,500 pa					
“Just affordable”	2½ to 3½	£35 to £70	½ over 60	C2 to E	2/5 in one-adult households
“Hard up low users”	1½ to 2½	£35 or less	¾ over 60	D and E	⅔ in one-adult households
“Unphoned”: half have income under £6,000 pa					
	2 to 2½		½ 20-40 ¼ over 60	D and E	

Source: Oftel (1995).

The Department of Transport (1988, p.26) suggested that car ownership depended on income, the number of adults in the household, socio-economic group, housing tenure and whether urban or rural. On average in 1953/4 better-off households spent a higher proportion of their budgets on cars. However, poorer middle and upper classes households seem to have afforded cars too (Table 7.3.4). But these figures are averaged over those who did not own cars. For those who did run cars, the proportion of budgets absorbed by cars was much higher. For example in 1954 a middle class reader of *The Manchester Guardian* (Manchester Guardian, 1954) with an income of £875 a year, or £17 a week reported: “I do indulge in the riotous luxury of running a car” “but going to work by car every day saves about ninety minutes in travelling time” and “is a great boon for outings and holidays”: the car cost £120 a year or 14 percent of gross income.

Table 7.3.4: Budget shares of cars by occupational status of head of household: UK: 1953/4.

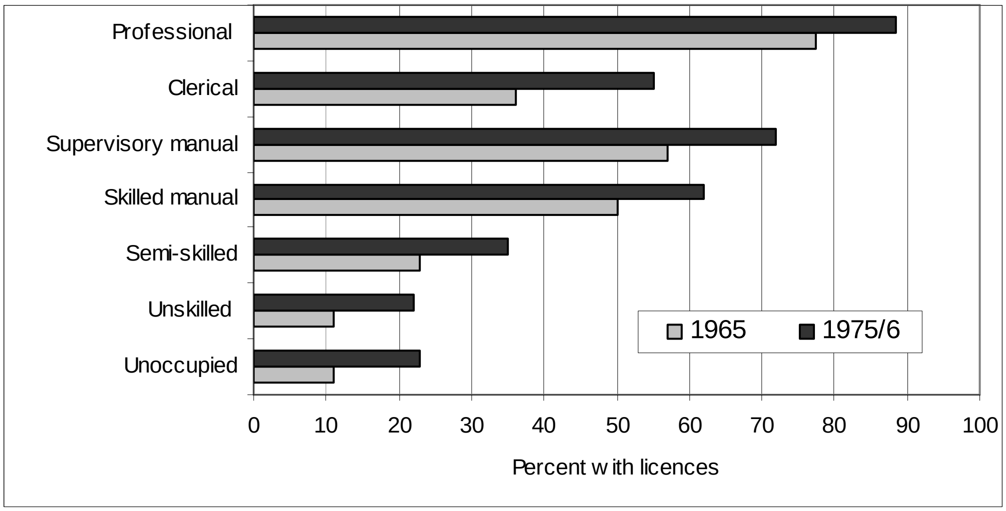
Status of head of household	**Gross weekly household income**						**Average budget £ pw**	**% house-holds**
	Under £8	£8-9	£10-13	£14-19	£20+	All		
Upper (1)	*	*	5.1	5.1	5.6	5.3	19	8
Middle (2)	5.0	4.8	4.9	4.6	3.9	4.5	14	10
Manual (3)	3.6	3.7	4.1	4.7	4.8	4.3	12	54
Own account	2.3	1.7	5.0	4.7	8.2	5.3	14	6
Retired etc	0.8	1.5	2.2	4.1	3.1	2.0	8	20
All	1.1	1.8	2.8	3.3	5.0	na	12	100

1. Employer/managerial 3. Incl. shop assistants
2. Professional, teaching, clerical * Less than 100 in cell

Source: Source: Ministry of Labour (1957, Tables 8, 25-29)

This class difference persisted. In 1965, professionals were eight times more likely to have had driving licences than the unskilled and unoccupied. While in 1965, some 80 percent of the professionals had licences, by the mid-1970s, the clerical and higher manual workers were catching up (Fig. 7.3.1).

Fig. 7.3.1: Driving licences by class: 1965 & 1975/6.



Source: DTp (1979, Table 2.2)

Between 1951 and 2001, the proportion of ABs and C has increased at the expense of DEs (Table 7.3.5). However, for simplicity it is assumed that throughout the period a quarter are ABs, representing the professional classes, a quarter DEs representing the semi-skilled and unskilled and a half are Cs, those in between.

Table 7.3.5: Social classes: 1951 and 2001.

	1951	2001
AB 1951: Classes I and II (which included senior civil servants, doctors, bankers, teachers and economists). 2001: Higher & intermediate managerial/administrative, professional.	20%	26%
C 1951: Class III which included foreman, typists, shop assistants. 2001: Supervisory, clerical, junior managerial/administrative, professional & skilled manual.	50%	54%
DE 1951: Classes IV and V which included agricultural workers, labourers, charwomen and drivers of horse-drawn vehicles. 2001: Semi-skilled & unskilled manual.	30%	20%

Sources: GRO (1952) & ONS (2009d).

Modelling Income

The overall distribution of income can be described by the Gini coefficient (as explained in Chapter 2). During the second half of the twentieth century, the Gini coefficient has fluctuated around a third (see Chapter 2). The aim is therefore to produce an income distribution consistent with a Gini coefficient around this level. The details of the modelling of the Gini coefficient are given in Box 7.3.1.

Box 7.3.1: Calculating the Gini coefficient.

The subprogram to calculate the Gini coefficient is taken from Wilensky's Wealth Distribution Model (2009) and can be described in pseudo-code as:

> Sort the households by income.
> Accumulate for each household in turn from the poorest to the richest, the rank of the household minus the proportion of the sum of the incomes of all households up to and including this household as a proportion of the total income of all households.
> Divide the result by twice the number of households to give the Gini index.

The code was verified by running an example, printing the resulting incomes for 1,000 households and applying Deaton's formula (Deaton, 1997, p139) to calculate the Gini coefficient:

$$\frac{N+1}{N-1} - \frac{2}{N(N-1)\mu}\sum_{i=1}^{N} p_i x_i$$

where N is the number of observations, μ the mean, p_i the rank of the ith observation, with the richest equal to 1 and, x_i the income.
In the example, the NetLogo program produced a Gini coefficient of 0.3128, and the calculation yielded 0.3131. Rounded to three decimal places, the results were the same.

The households in the model are divided into mutually exclusive economic activity status categories based on the economic position of the head of the household:

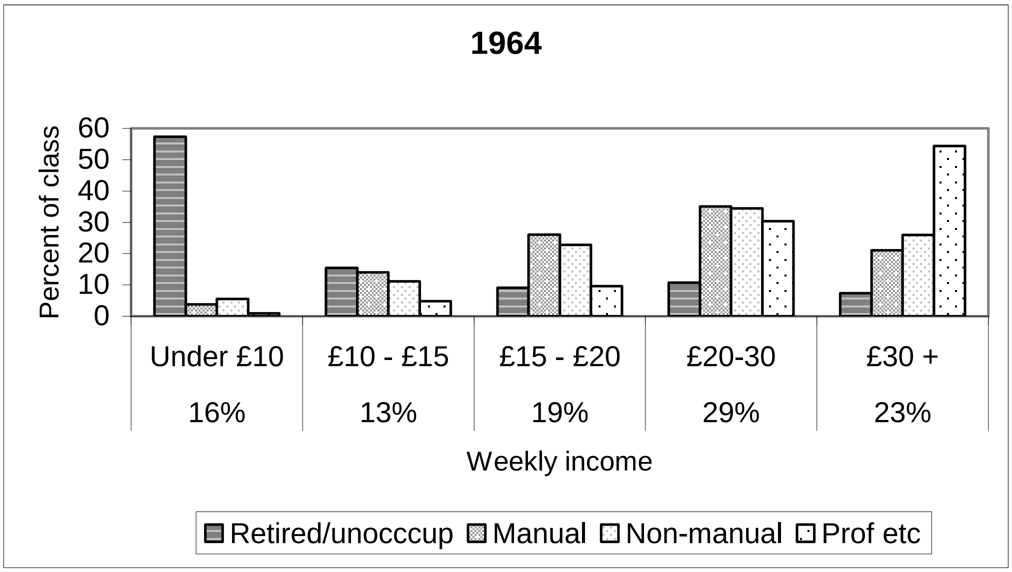
- the economically active, who are either working or temporarily unemployed;
- the economically inactive under age 65 – the 'unoccupied' – who are long-term unemployed, sick or disabled, lone parents or early retired;
- all those over 65 are deemed to be retired.

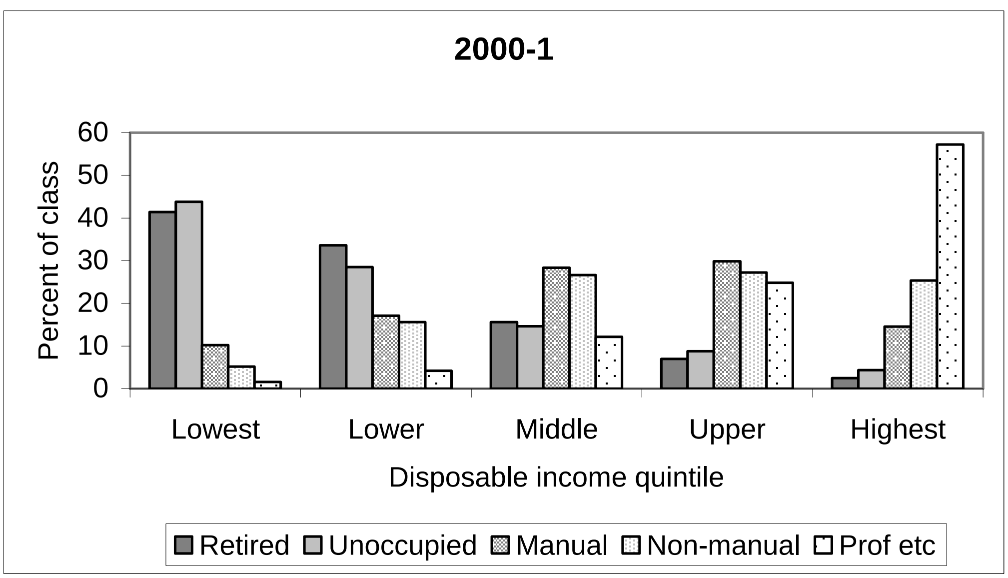
First, earners are discussed, followed by the unemployed, the unoccupied and the retired.

In this model income is based on social class. While it is generally true that the higher the class, the greater the income, there is considerable variation in incomes within classes as shown in Fig. 7.3.2. For example in 2001, nearly 6 out of 10 of those in the "professional" class were in the top income quintile but a few were in the bottom quintile.

Fig. 7.3.2: Income and social class: 1964 and 2000-1.

Example.
In 1964, 23% of all households had an income of £30 or more per week. However, just over half of the professional households were in this top income band. (Analysis by quintile is not available) In 2000-1, just over half of professional households were in the highest quintile of the distribution of disposable income.





Sources: Ministry of Labour (1965), ONS (2002) (Data is available for intervening years and shows a similar pattern: but not available for 2001-2. (ONS, 2003a).)

Details of the basic modelling of income are shown in Box 7.3.2.

Box 7.3.2 Allocating income by class.

The income figure is an index number. To generate a Gini coefficient of about a third, with an overall average income of 1, a distribution of income is generated for each class using a normal distribution with the following means and variances, based on the data below:

- Class AB: mean 1.6, variance 0.6
- Class C: mean 1, variance 0.4
- Class DE: mean 0.8; variance 0.35

Ratio of household income (or expenditure) to average by occupational group: 1971 to 2001

Occupation	1971	1981	1991	2001
Professional & managerial	1.44			
Professional		1.53	1.72	1.76
Adminstrative/managerial		1.51		
Employers/managers			1.71	1.68
Intermediate non-manual			1.29	1.29
Junior non-manual			1.04	0.99
Clerical	1.07	1.07		
Manual	1.03		0.99	0.95
Skilled		1.09	1.11	1.09
Semi-skilled		0.95	0.85	0.85
Unskilled		0.81	0.74	0.67

Sources: DE (1972 & 1982), CSO (1992), ONS (2002)

Second earners

Fischer (1992, p.117) suggested that phones were more likely in households were there was more than one earner, especially if the additional earners were women. In 1951 only about a fifth of married women were economically active; by 1991, over a half were (Gallie, 2000, p.292). By 2001, given the extent of unmarried cohabitation, it is no longer meaningful to look at the economic activity rate of married women; but 60 percent of all women were then economically active, rising to 75 percent of those aged 25 to 54 (ONS, 2009d). (Details in Box 7.3.3)

Box 7.3.3: Modelling economic activity of second earners.

Initially 25% of 'wives' under 60 work and 10% of those over 60 are assumed to have worked in the past.

Each year the activity rates are increased as indicated in the table on the right and thus more wives under 60 go out to work.

Once wives work, they are assumed to continue.

On retirement, the second earner's contribution continues, reflecting a pension.

	Under 35		35 and over	
	Economic activity rate	Annual growth	Economic activity rate	Annual growth
1951	25%	2.5%	25%	2.5%
1961	33%		33%	5%
1971	40%		50%	2.5%
1981	50%	1.5%	66%	0.5%
1991	60%	2.0%	70%	
2001	75%		75%	

The model also has to assume how much these 'working wives', to use the terminology current for most of the period under discussion, contributed to household income. As the proportion of married women working increased, so did the proportion working part-time: in 1961, 40 percent of economically active married women were working part-time and by 1971 this had risen to 50 percent (Hamill, 1978a).

Because of the prevalence of part-time work together with the lower average pay of women, in 1974, on average working wives contributed 25 percent to the family income and few women accounted for more than half, as shown in Fig. 7.3.3 (ibid). This implies that the incomes of households with working wives raised household income by one-third on average.

Fig. 7.3.3: Working wives' contribution to family income: 1974

Source: Hamill (1978a)

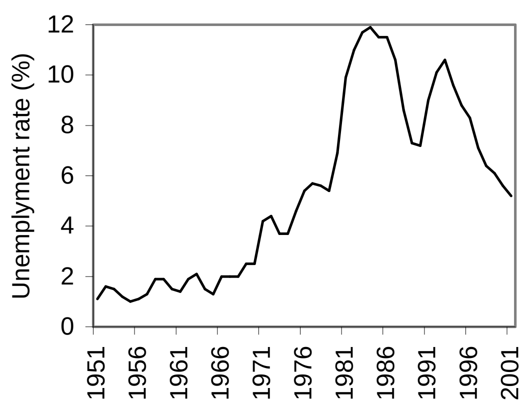
More recent work, such as Arber & Ginn (1995), has focused on the difference between husbands' and wives' earnings rather than the wife's contribution to total household income, which takes into account income from sources other than the husband's employment. So for those households where there is a second earner, their contribution is allocated randomly but uniformly between 1 and 50 percent, to give an average of 25 percent.

Furthermore, there might be adult children living at home. For example, in 1951, half the non-retired households containing more than one person included more than one earner (GRO, 1952, Table V.5). It is not clear how much such earners contributed and a more complicated model of household structure would be needed to accommodate this effect. However, it is taken into account indirectly in that some lower class households do have high incomes (as shown in Fig. 7.3.2), and in real life this would probably be associated with the presence of additional earners.

Unemployed, unoccupied and retired

Time series on unemployment are plagued by changes in definitions and benefit eligibility (Gaillie, 2000, pp.311-6). However, in broad terms, unemployment was "unprecedentedly low" (Gallie, 2000, p.315) in the 1950s and 1960s, but thereafter rose to much higher levels shown in Fig. 7.3.4.

Fig. 7.3.4: Unemployment rates: 1951-2001.



Sources: Feinstein (1972), Gallie (2000) & ONS (2009b, series YBTI).

However, the rates shown in Fig. 7.3.4 are for all workers but youth unemployment tends to be significantly higher than for older workers. Rates for prime age workers tend to be about four-fifths of these rates and as the model is confined to those over 24, these lower rates are used. Furthermore, unemployment varies by class. Based on data from 1991 to 1997, Gallie (2000, p.317) concluded that "professionals were the least likely of all to be unemployed" and "by far the most vulnerable were the craft, operative and non-skilled workers". These "non-skilled" were three times more likely to experience unemployment than "managers" while professionals were about half as likely. This effect, too, is taken into account. Box 7.3.4 shows the detailed assumptions made in the model. The high unemployment rates assumed for the DEs in later years means that some of these households move in and out of poverty frequently. This is consistent with findings from analysis of the British Household Panel Survey which found that “almost one fifth” were “poor at least twice in the six year period studied” (Jenkins, 2000).

Box 7.3.4: Modelling unemployment.

Each year, 95% of those who were unemployed last year return to work and the remaining 5 % become unoccupied. The appropriate unemployment rates are then applied again.

	1951-70	1971-80	1981-2001
Average unemployment rate (Fig. 7.3.9)	1.7	5.0	9.0
Target base rate (0.8 x average)	1.3	4.0	7.2
Assumed rate for			
- ABs (0.6 x base rate)	0.6	1.7	3.1
- Cs (base rate)	1.0	2.9	5.2
- DEs (3 x base rate)	2.9	8.7	15.5
Rates used in model	0.95	2.90	5.15

Walling (2004) reported that 16 percent of “working age households” in 2004 “had no adult member in work”. Following Walling (2004), the model identifies three basic groups of unoccupied:

- The early retired. The economic activity rates of those approaching retirement has fallen throughout the period (Johnson & Zaidi, 2007). In 1951, 91 percent of men aged 55 to 64 were in employment. (GRO, 1952, Table II.3). By 1979, just over 80 percent of men aged 50 to 64 were employed or self-employed and by 2001, about 70 percent (ONS, 2005). The model assumes that initially 5 percent of households aged 50 to 64 are early retired and this rises by ½ percent each year, to reach 30 percent by the end of the period.
- One parent families. The number of one parent families is determined by the demographic part of the model. The proportion of one parent families in work seems to have stayed the same: in 1978 half of lone mothers worked compared to only a third of married mothers (Hamill, 1978b); in 2008, half worked (ONS, 2008c). So the model assumes that half are economically active throughout the period.
- Disabled and long-term unemployed. In practice, these two groups are difficult to distinguish: people who are unable to work due to health problems may be classed

as unemployed or sick depending on the prevailing benefit entitlement rules (Webb, 2000, p.569). The model assumes that 1 percent of households are long-term sick and that each period, 5 percent of the unemployed become long-term unemployed and in effect leave the labour force.

In the model, once households become unoccupied, they are assumed to remain so until they reach retirement. While that is probably a good assumption for the early retired, it is less valid for others.

Unemployed, unoccupied and retired households on average have lower income than those in work. For a single person, the basic state pension and other benefits have tended to be around a quarter or less than average earnings (Pensions Commission, 2005, p.45; Webb, 2000, pp.574-5). However, due to the skewed income distribution, the earnings of the majority are below average. Thus the 'replacement ratio' – the extent to which benefits replace income – is higher. Furthermore, households may have other types of income, such a child benefit or occupational pensions. Blundell & Tanner (1999) reported that replacement ratios could be as high as three-quarters for poorer people retiring around 1990, falling to a half for the better off. According to the Department of Work and Pensions (2008), in 2006 the ratio of median personal income from pensions of those aged 65 to 74 to median personal income from earnings of those aged 50 to 59 was 0.44.

Data from 1971 to 2001, shown in Table 7.3.6, shows various ratios of income or expenditure for old and retired people to the average for all households. On the basis of this evidence, it is assumed that incomes halve when households become unemployed, unoccupied or retire. (An alternative assumption of a drop to one-third produced a Gini coefficient that was higher than the targeted rate.)

Table 7.3.6: Income or expenditure of older households compared to average: 1971-2001.

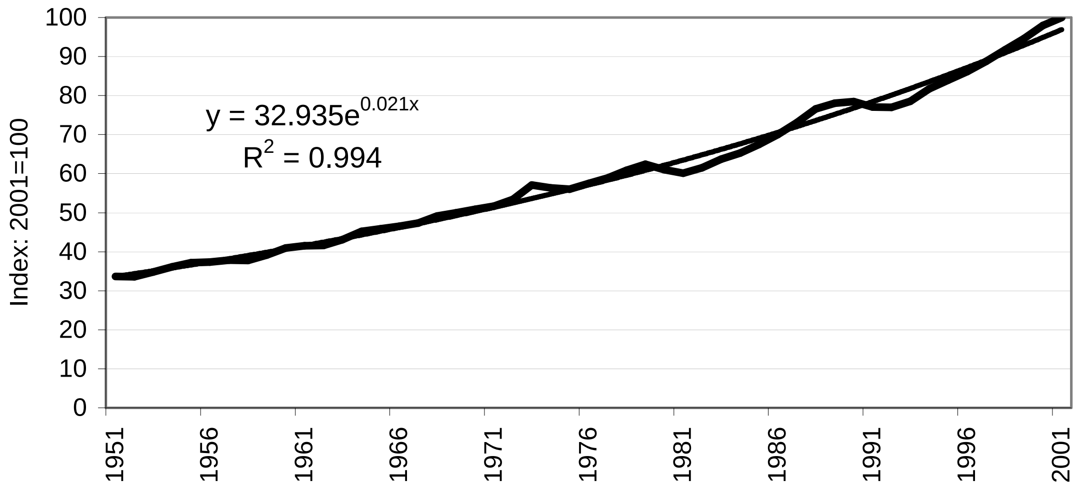
All households	**1.00**
1971	
65+	0.59
Single person h'holds	0.36
Two person h'holds	0.64
1981	
65+	0.57
Single person households	
Men 65+	0.42
Women 60+	0.36
1991	
Retired	0.55
2000-1	
Retired	0.56
65-74	0.67
75+	0.51

Sources: DE (1972 & 1982); CSO (1992); ONS (2002) 1971: expenditure; others on income.

Income growth

From 1951 to 2001, real GDP per head grew by 2 percent a year on average as shown in Fig. 7.3.5. This means that real income in 2001 was 2.7 times that in 1951. Of course, the increased economic activity of wives will have contributed to this but for simplicity, this is ignored in the model and it is assumed that incomes rise at 2 percent a year.

Fig. 7.3.5: Real GDP per head: UK: 1951-2001.



Sources: Feinstein (1972); ONS (2009b, series IHXW).

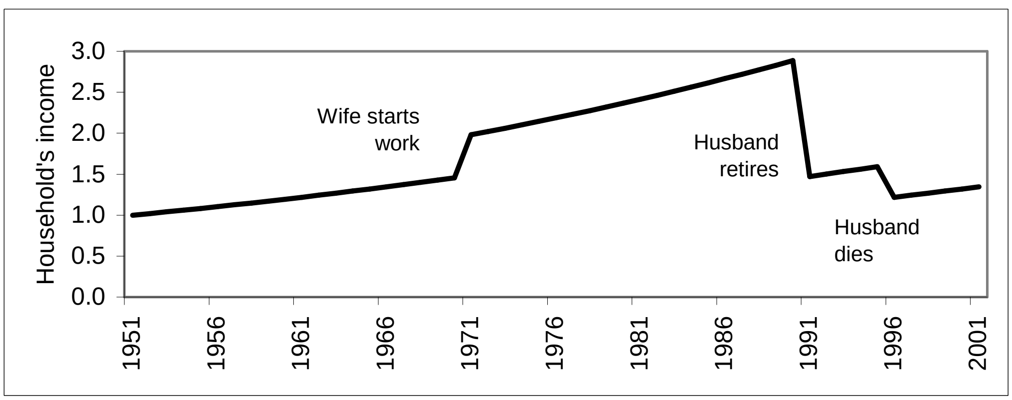
A minimum income level is set below which no households are allowed to fall: this is one quarter of average income in 1951, rising with economic growth. This level is consistent with benefit levels: for example, in 1971, the supplementary benefit allowance, widely but not officially regarded as the poverty line, for a single person represented 20 percent of average earnings, although it has since fallen (Webb, 2000, pp.574-5).

Box 7.3.5 gives an example of how, in the model, household income might change over time and demonstrates the dramatic effect of economic growth of 2 percent a year over 50 years. It is simplistic in that it does not allow for the change in relative earnings as people age (see for example, Johnson & Zaidi, 2007). (For other ways of modelling household income over time, see Evans & Eyre, 2004, Box 1.1.)

Box 7.3.5: Example of changing income.

The income figure is an index number, with 1 taken as the average in 1951. The example taken is a household comprising a married couple with the husband aged 25 in class C on average income i.e. an income of 1 in 1951.

Event	Income	Calculation
1971: wife starts work and her contribution is 25 percent.	1.98	Given the cumulative growth rate of 2 percent a year, the household's income will have increased to $1 \times 1.02^{20} = 1.49$ The wife working raises the household's income to $1.49 / (1 - 0.25) = 1.98$
1991: husband reaches 65	1.47	Income has grown at 2 percent a year to reach $1.98 \times 1.02^{20} = 2.94$ Retirement halves the income to 1.47
1996: husband dies	1.22	The income will have risen to $1.47 \times 1.02^{5} = 1.63$ The income is reduced by the wife's contribution rather than the husband's as the widow will receive a pension. The income will then be: $1.63 * (1 - 0.25) = 1.22$
2001: widow dies	1.35	The household income will be $1.22 \times 1.02^{5} = 1.35$.



Results

This model produces distributions of income that are broadly in line with those observed. The initial income distribution has a mean of one and a Gini coefficient of about a third. Further initial figures are shown in Table 7.3.7: the incomes of the top quintile are more than 1½ times the average while those of the bottom quintile, below half average and broadly replicate the class distribution shown in Fig. 7.3.2.

Table 7.3.7: Model results: initial income distribution.

Initial values		**Mean**	**sd**
Bottom decile		0.4	0.01
Bottom quintile		0.5	0.02
Median income		0.9	0.02
Mean income		1.0	0.02
Top quintile		1.5	0.04
Top decile		1.9	0.05
Average over 50 years	**Target**		
Percent in bottom quintile			
AB	Almost none	2	0.5
C	About 5%	5	1.8
DE	More than Cs	10	2.5
Unoccupied	About half	32	5.6
Retired	About half	49	2.0
Percent in top quintile			
AB	At least half	62	0.9
C	About 20%	17	2.0
DE	Less than Cs	7	1.2
Percent AB% in top 2 quintiles	At least 75%	82	1.0

Fig. 7.3.6 shows how the proportion of economically active households in the model declines over the period. On this basis, by 2001, some 15 percent of households are unoccupied, broadly consistent with Walling's (2004) estimate that 16 percent of "working age households" in 2004 "had no adult member in work". The Gini coefficient (Fig. 7.3.7) fluctuates around a third but does not track the fall under the 1970s Labour Government and rise under the 1980s Conservative Government as these details were not programmed.

Fig. 7.3.6: Model results: economic activity of households.

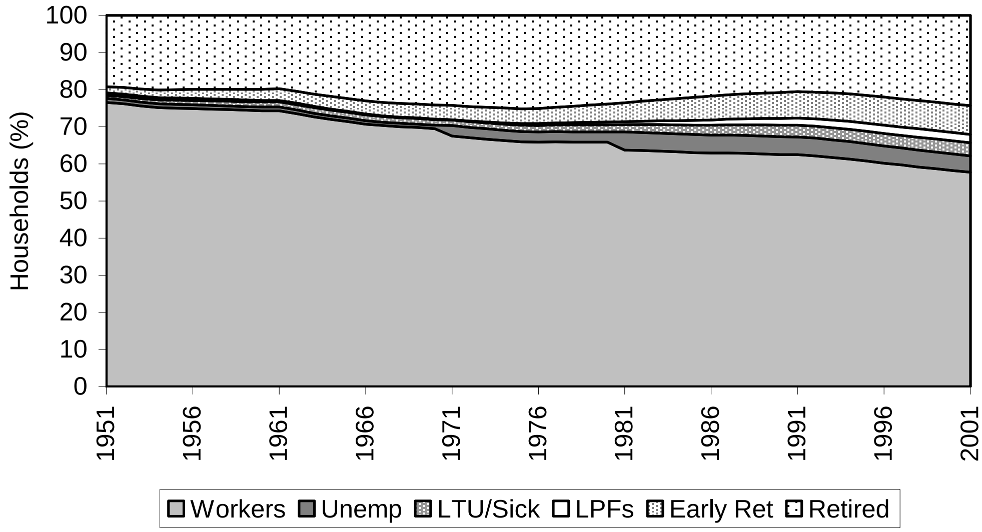
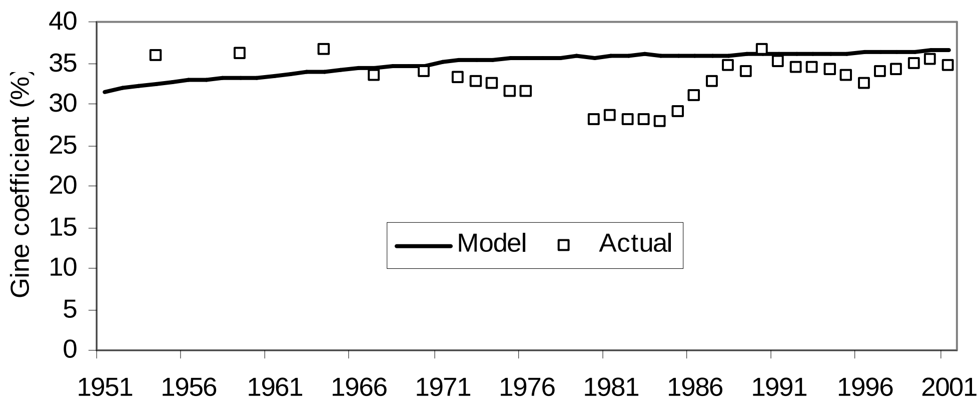


Fig. 7.3.7: Model results: Gini coefficient.



Sources: actuals: Atkinson (1980), Jones (2008).

7.4 Modelling Adoption

Having established the size, class and income of the households, the next stage is to generate the model of adoption as set out in Chapter 5. This Section therefore looks at availability, affordability, skills and personal networks.

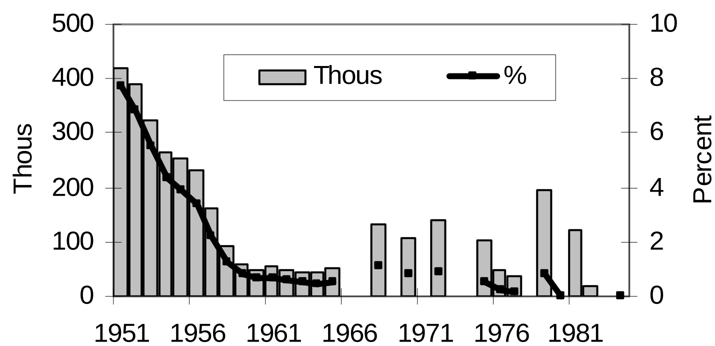
Availability

There were waiting lists for phones in Britain up until the privatisation of BT in 1984, due to “the unavailability of telephone exchange equipment” (Hansard, 1973). In 1951, nearly half a million were waiting for a phone connection. By 1975, the Government was claiming that at 76 thousand, the waiting list was at its lowest for ten years (Hansard, 1975). Waiting lists were still an issue in the early 1980s (Hansard, 1983):

> “The waiting list for the provision of business and residential telephone service has been reduced from 122,400 as at 31 March 1981—equivalent to 7.9 per cent. of the annual demand for exchange connection service—to 20,100 as at 31 March 1982—1.4 per cent.—and to 5,100 as at 31 January 1983—0.4 per cent.”

By May 1984, the waiting list was finally reduced to just 337 (Hansard, 1984) and in the 1990s there seem to have been no complaints in Parliament of waiting lists for phones. The figures cover both business and residential phones and are summarised in Fig. 7.4.1. This means that any model should overestimate phone adoption in the 1950s, especially the early 1950s, because some of those who wanted phones were unable to obtain them.

Fig. 7.4.1: Waiting lists for phones: business and residential: 1951-1984.



Sources: Hansard (1965, 1968, 1972, 1975, 1978, 1983 & 1984), Mitchell 1988.

In 1951, there were already nearly 300 thousand kilometres of roads: by 2001, this had increased to 400 thousand kilometres, an increase of just half a percent a year (DfT, 2007b, Table 7.6). Most of this increase was accounted for by unclassified roads on new housing estates. The important change was the introduction of motorways from the late 1950s. By 2001, there were 3½ thousand kilometres of motorways, most having been built between 1961 and 1991 (ibid). Motorways reduced the time needed for long-distance journeys. In the 1950s "roads were poor and still served local needs rather than those of national travel (Marwick, 1990, p.33). I recall how a journey in the 1950s from Oxford to South Wales via Gloucester took a full day; I recently did the same journey, using the Severn Crossing, and it took just a morning. By 1995, even though motorways accounted for less than 1 percent of road length, they carried 15 percent of car (and taxi) traffic (measured by kilometres travelled) (DTp, 1996, Table 4.9; DfT, 2007b). The important change over the fifty years was therefore an increase in the quality of roads.

Affordability

There is no simple 'price' of a phone or a car. The cost of a phone is a combination of the standing charge and the cost of calls, while for a car there are capital and running costs, as illustrated in Table 7.4.1 for the mid-1990s. The obvious point is that cars cost much more than phones.

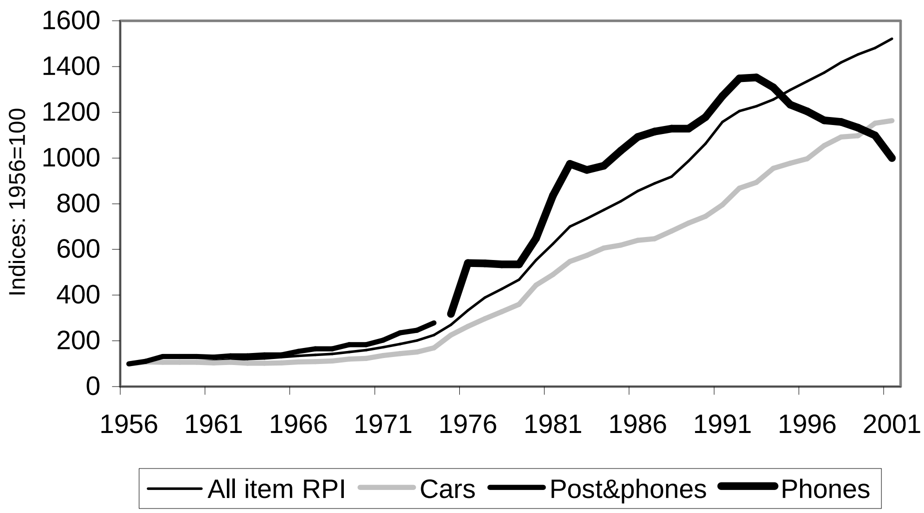
Table 7.4.1: Costs of phones and cars, mid-1990s.

	Phones			Cars		
		£	%		£	%
Fixed costs	Per quarter			Per year		
	Connection &			Road tax	150	7
	takeover charges	0.97	2	Insurance	264	13
	Line rental	21.09	44	Depreciation	1,024	50
	Total fixed	22.87		Total fixed	1,438	
Variable	Per quarter					
costs				Petrol	0.0760	18
	Local calls	14.14	30	Other	0.0499	12
	National calls	9.07	19			
	International calls	2.16	5	Total variable for		
	Total variable	25.37		5,000 miles	630	
Total	Per quarter	47.43	100			
	Per year	190		For 5,000 miles	2,068	100

Source: Phones. median quarterly residential bill: 1994/95: Oftel (2001a)
Cars: up to 1100 cc doing 5,000 miles a year AA (2008)

Despite this complexity, the prices of phones and cars have been included in the retail price index (RPI) since the 1950s (O'Donoghue et al, 2006). Initially phone prices were combined with postal charges so a phone price index is available only from 1974. Between 1951 and 2001, the RPI rose almost twenty-fold (ONS, 2009b, series CDKO). However, as Fig 7.4.2 shows, the prices of phones and cars followed very different paths. Oftel (1997) reported that between 1984 and 1997, although rental charges increased slightly in real terms, call charges fell by up to four-fifths in real terms. Thus price of phones relative to the RPI fell from 1993. The relative price of motoring also fell sharply, but only in the first half of the period. Falling relative prices encourage demand.

Fig. 7.4.2: Relative prices of phones and motoring: 1956-2001.



Sources: To 1987: O'Donohgue et al (2006). From 1987, ONS (2009b, series CHAW, DOCH & CHBK)

So in real terms, both phones and cars were much more affordable in 2001 than in 1951. For cars, Root (2000, p.449) summed it up well:

> "The fall in the cost of cars relative to income has been a fundamental driving force behind the growth in car ownership. Cars were cheaper to run and more fuel efficient in 1996 than 30 years earlier. Car prices dropped 25 percent since 1964. The cost of fuel was about the same…but at the end of the century cars were more fuel efficient and cheaper to run, and average incomes had grown by about 2 percent a year in real terms. This meant that the proportion of an average household's gross income required to own and operate a car fell by about 40 percent between 1964 and 1996."

Table 7.4.2 illustrates this point, although it does not include all the costs associated with motoring.

Table 7.4.2: Cost of motoring: tax and petrol: early 1950s and 2001.

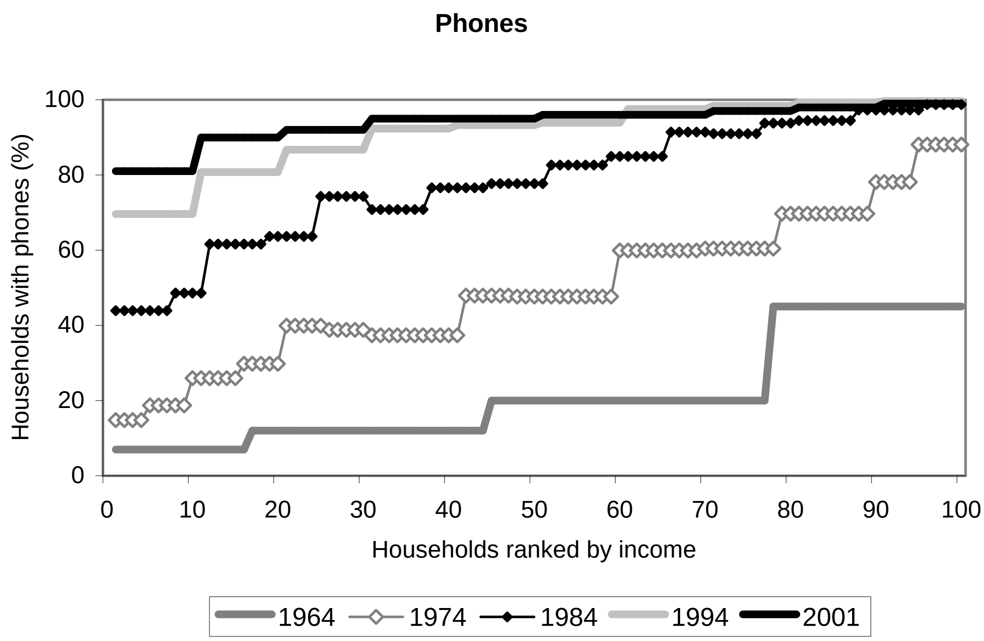
	Early 1950s	2001
Annual Road Fund tax (1950)	£10	£105 (small car)
Litre of petrol (1950)	3.3p	75p
Average weekly household expenditure	£12	£390
Annual Road Fund tax as % average weekly expenditure	80%	37%
50 litres of petrol as % average weekly expenditure	138%	10%

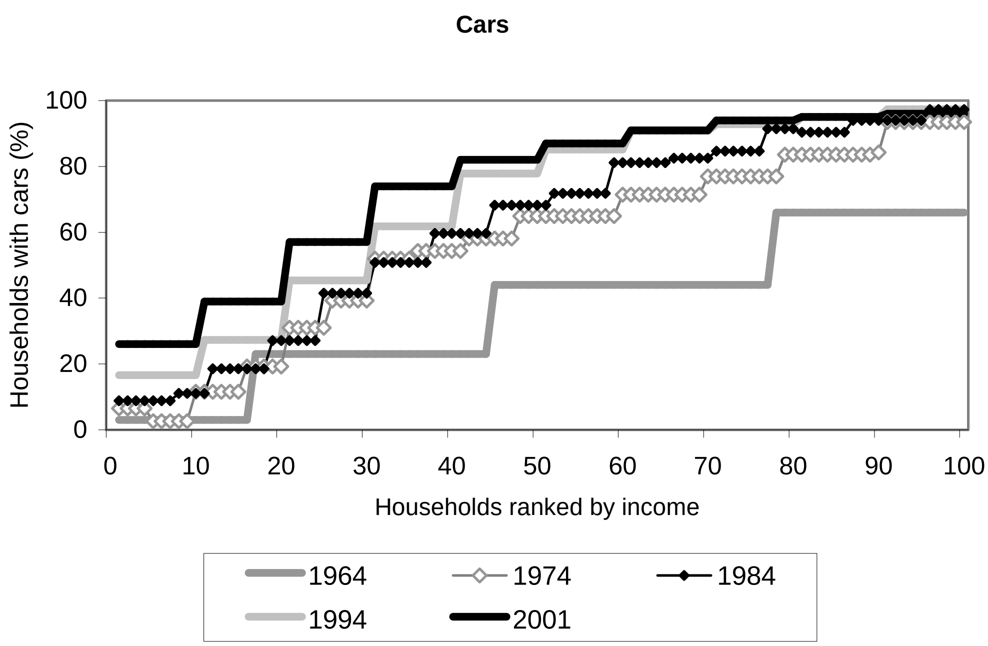
Sources: Ministry of Labour (1957); AA (2008); ONS (2002)

Yet, despite the relative expense of cars, as already noted, in 1951 more households had cars than phones: 14 percent of households had cars while only 10 percent had phones. Even by 1964, households at all income levels were more likely to have cars than phones. The adoption of phones crept up the income scale gradually over the 30 years between 1964 and 1994. However, the adoption of cars jumped between 1964 and 1974 with little growth in adoption at any income level after that. (Details in Fig. 7.4.3.)

Again, affordability is taken as an absolute rather than a relative measure, because as the economy grew, the poor could afford things that were previously the preserve of the rich. In the model households whose income exceeds the affordability threshold can adopt. Taking the different scale and composition of the costs of phones and cars and the different patterns of diffusion, different thresholds are needed for cars and phones. For cars affordability is driven by the growth in real income and the fall in relative price. When income exceeds the threshold, a car is bought. If income subsequently falls below two-thirds of the prevailing threshold due to retirement or becoming unoccupied, the car is sold. If income were the main constraint, then far more households would be expected to have had phones than cars. The income thresholds were therefore established by experimentation as described in the next Section.

Fig. 7.4.3: Phone and car adoption by income: 1964 to 2000-1.





Sources: Ministry of Labour (1965); DE (1975 & 1986); CSO (1995) & ONS (2002).

Skills

A licence is required to drive a car. People obtain licences because they want to drive. Passing the driving test is a specific skill, in contrast to becoming literate which is a general skill. Thus whereas in Chapter 6 literacy was modelled separately, in this model the holding of driving licences is not modelled directly.

Table 7.4.3: Driving licences by age: 1975/6 to 1998/2000.

Percent

	Age	
	60-69	70 or over
1975/1976	35	15
1985/1986	47	27
1989/1991	54	32
1992/1994	57	33
1995/1997	63	38
1998/2000	67	39

Source: DfT (2006a, Table 9.16)

There will always be people who cannot hold licences for legal or, more importantly, medical reasons, especially as they age. Since at least the mid-1970s, those aged 70 and over tended to be half as likely to hold licences as those in their 60s (Table 7.4.3). However, it is not possible to distinguish between those who gave up driving due to frailty and those who gave up because they could no longer afford a car. The rule in the model that requires households to sell their cars when their incomes fall below a certain level will deal with the former. To deal with the latter, it is assumed that no households aged 75 or over have cars.

Personal networks, mobility and tastes

Even if people have the same income, they will not buy exactly the same things due to what economists call 'tastes'. Tastes are influenced by many factors, including those in your personal network. Fischer (1992, p.113) noted that even though cars were more expensive than phones, "working class families bought sooner and more often kept automobiles than they leased telephones". In contrast phones were "an expected item in middle class homes" in the US by around the time of the First World War (Fischer, 1992 p.189). In 1933, Willey & Rice commented "to be without a telephone or a telephone listing is to suffer a curious isolation in the telephone age" (cited in Fischer, 1992, pp.26 & 190). Fischer (1992, p.117) also suggested that phones were more likely in households where there was more than one earner, especially if the additional earners were women.

While the additional income increased the affordability, the fact that it was additional female earners that was important suggests that there is another factor at work too. Fisher (1992, pp.226-235) concluded that in the US in the first half of the twentieth century phones were often used by women for social purposes.

Turning to the UK, Young and Wilmott's 1950s studies suggested that there might have been a similar effect. Young & Wilmott described the impact of moving from Bethnal Green to a new estate at 'Greenleigh' "less than twenty miles away" in the mid-1950s (1957, p.97). They reported that "the Bethnal Greener's society is close by. He does not need a telephone to make appointments to see his friends because they are only a few minutes away" (Young & Wilmott, 1957, p.130). Consequently there were only 13 "residential subscribers" per thousand in Bethnal Green compared to 88 in Greenleigh and the Greenleigh respondents reported that keeping in touch with kin was one reason. Furthermore at Greenleigh "distances to shops, work and relatives are not walking distances any more. They are motoring distances: a car, like a phone, can overcome geography" (Young & Wilmott, 1957, p.131). They noted that "cars are beginning to move from luxury to necessity". Thus they concluded that "cars, telephones, telegrams and letters represent not so much a newer and higher standard of life as a means of clinging to something of the old" (ibid, p.132). Dyer (2007) found that even in the 1990s, inner city households were less likely to have phones, which he attributed to poverty but he did not discuss social networks.

Following their examination of a London suburb, Wilmott & Young (1960, p80) argued that "cars, telephones and letters are all means by which middle-class people can straddle the distance they have interposed between themselves and their relatives". Bell (1968, p.86) noted that of the 120 middle class families he studied in Swansea in the mid-1960s, "all but four" had "at least one car" and "all but nine had a telephone". Goldthorpe (1987, p.168) expanded on this theme: mobile men, he pointed out, do not drop ties of kinship even though those kin may be separated geographically. In 2000, non-manual workers were less likely than manual workers to have friends and relatives living nearby and were more likely to contact them by phone weekly; and households with cars were also less likely to have close relatives living nearby and more likely to phone them at least once a week than households without cars (Table 7.4.4).

Table 7.4.4: Contact with friends and relatives by class and car ownership: GB: 2000.

Percent

	S.e.g.(1)		Cars available to household			All
	Non-manual	Manual	None	One	Two plus	
Relatives						
Close relatives live near	50	66	60	57	54	56
See relatives at least once a week	59	71	64	65	60	63
Speak to relatives on phone						
Daily	26	29	31	28	24	27
Not daily, but at least once a week	58	52	47	57	58	55
Less than once a week	15	19	21	15	18	17
Friends						
Close friends live near	70	76	74	73	74	73
See friends at least once a week	74	76	73	76	76	76
Speak to friends on phone						
Daily	20	19	20	20	22	21
Not daily, but at least once a week	60	53	49	58	60	56
Less than once a week	20	28	31	22	19	23

Source: Coulthard et al (2002)
(1) Socio-economic group.

In the second half of the twentieth century, those who migrated could keep in touch with family and friends left behind without using phones or cars, but by using those nineteenth century methods, mail and rail, discussed in Chapter 6. The new methods of communication and travel, phones and cars, enabled people to keep in touch better and, as described above, were regarded as an integral part of middle class life. It was arguably no coincidence that the middle classes were more mobile.

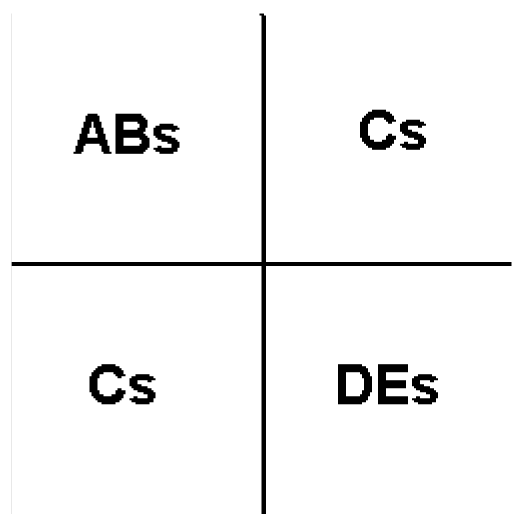
Consequently, rather than trying to model mobility, both social and geographical mobility are assumed to be a part of middle class culture. To reflect this in the model, the three classes are grouped together in the social space; ABs in one quadrant, DEs in another and the C's in the remaining two as illustrated in Box 7.4.1. As the households are distributed randomly, this will produce the 25/50/25 percent split between ABs, Cs and DEs respectively as described in Section 2. It also ensures that each household's personal network will be dominated by similar others. As in Chapter 6, socialshifting is assumed at the rate of 5 percent each year.

As noted in Chapters 3 and 5, there is little point having a phone unless those in your personal network also have phones. As discussed in Chapter 3, the size of personal networks depends on the criteria used. In this case study, the personal network of interest is very specific and narrow, namely those who will be influenced to adopt a phone. There is no direct evidence on this although "AT&T research shows that half of the calls from any given residence go to only five numbers" (Fischer, 1992, pp.225-6). The size of the influential personal network was therefore established by experimentation as discussed in the next Section. However, it is clear that households containing more than one person will tend have larger personal networks than single people; there are likely be more kin for example. The model allows larger households to have larger networks. Reflecting the history of phone adoption, adoption starts with the upper class, the ABs. To sum up, in the model phones spread through personal networks, subject to income being above the threshold, starting with a 'seed' AB household. (Details in Box 7.4.1.)

Box 7.4.1: Modelling the spread of the phone network

The ABs are distributed in the top left hand quadrant and the DEs in the bottom left hand quadrant. The Cs occupy the rest of the space. (Because the grid wraps round, the fact that the minorities are in 'corners' does not matter.)

The model assumes that a seed household of social class AB has a phone. A phone network is then grown through the personal network of this household until about 100 households – 10 percent – have phones. These may not necessarily be AB households but they must have an income above the appropriate threshold.



Summary of the model

The key features are summarised in Box 7.4.2. The income thresholds and the sizes of personal networks are set by experimentation, discussed in the next Section.

Box 7.4.2: Summary of whole model.

Initialisation

1,000 agents are used to represent households, in a space giving a population density of about 1 percent.

Class, household type and income determined.

To give a 25/50/25 percent split by class, households in top left quadrant designated class AB, in bottom right quadrant, class DE. Others, class C. (See Box 7.4.1.)

Households allocated type (one-person or multi-person; single or couple) and ages. (See Box 7.2.2.)

Incomes are distributed following social class, subject to a minimum, to reproduce a Gini coefficient of about a third (see Box 7.3.2). Allowing for:
- second earners (see Box 7.3.3) contributing an average of 25% of household income.
- unemployment (see Box 7.3.4).
- early retirement: 5 percent of households aged 50 to 64.
- half the lone parents economically active.
- 1 percent of households long-term sick.
- retired have half income of workers.

A “seed” class AB household selected and phone network comprising about 10 percent of households built through personal networks, subject to affordability.

Initial distribution of cars determined based on income. No cars allocated to those aged 75 plus.

Execution

Households age, split, combine and die. (See Boxes 7.2.1 and 7.2.2.)
5% percent of households socialshift each year.
Replacement households are created.
Incomes are determined:
- the proportion of second earners rises from about a half to three-quarters. (See Box 7.3.3.)
- unemployment rises 5 percent of the unemployed become long-term unemployed i.e. unoccupied. Most unemployed return to work and are replaced by newly unemployed. (See Box 7.3.4.)
- percent of households aged 50 to 64 who are early retired rises by 0.5 percent each year, reaching 30 percent by the end of the period.
- those still working at 65 retire and their income halves.
- incomes grow at 2% a year.

Phone adoption spreads through personal networks subject to affordability: if a neighbouring household within the appropriate social reach has a phone and if the household can afford a phone, then that household adopts. Once adopted, the phone it is kept. (See Box 7.4.1.)

Households’ ability to afford cars is recalculated: adopting if income has risen above the threshold, giving up if it has fallen too far below the threshold or age 75 reached.

7.5 Results

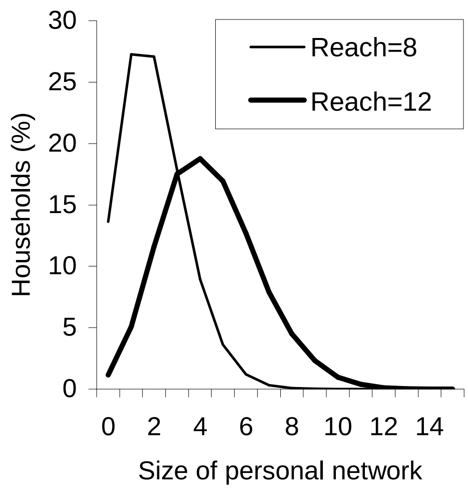
Basic results

As explained in the previous Section, the income thresholds for phones and cars and personal network sizes were set by experimentation. The results were:

- The income threshold for phones was set at 0.35 (i.e. 35 percent of the 1951 average, set at 1); according to the model, in 1951, 90 percent of households had incomes above that level. Given real growth of 2 percent a year and a minimum income of 0.25 (i.e. 25 percent of the 1951 average), by 1968 all households had incomes above that level and so income no longer constrained phone adoption.
- By 1951, 14 percent of households had cars. Given the distribution of income in the model, this suggests the threshold could have been between 1.5 and 1.9 (see Table 7.3.7). For cars, the threshold is set initially at 1.65 but falls to 1.25 by 1973 to reflect the falling price of motoring (noted in Section 4); specifically, between 1958 and 1965, the threshold falls by 2½ percent a year and then by 1 percent a year to 1973.
- Personal networks

The best result, based on ordinary least squares (OLS), was obtained with social reach for one-person households set at 8, implying an average size of 2 (s.d. = 0.08); for multi-person households, the social reach is set at 12 implying an average personal network size of 4½ (s.d. = 0.10). The distributions of sizes are shown in Fig. 7.5. 1.

Fig. 7.5.1: Base case: distribution of personal networks.

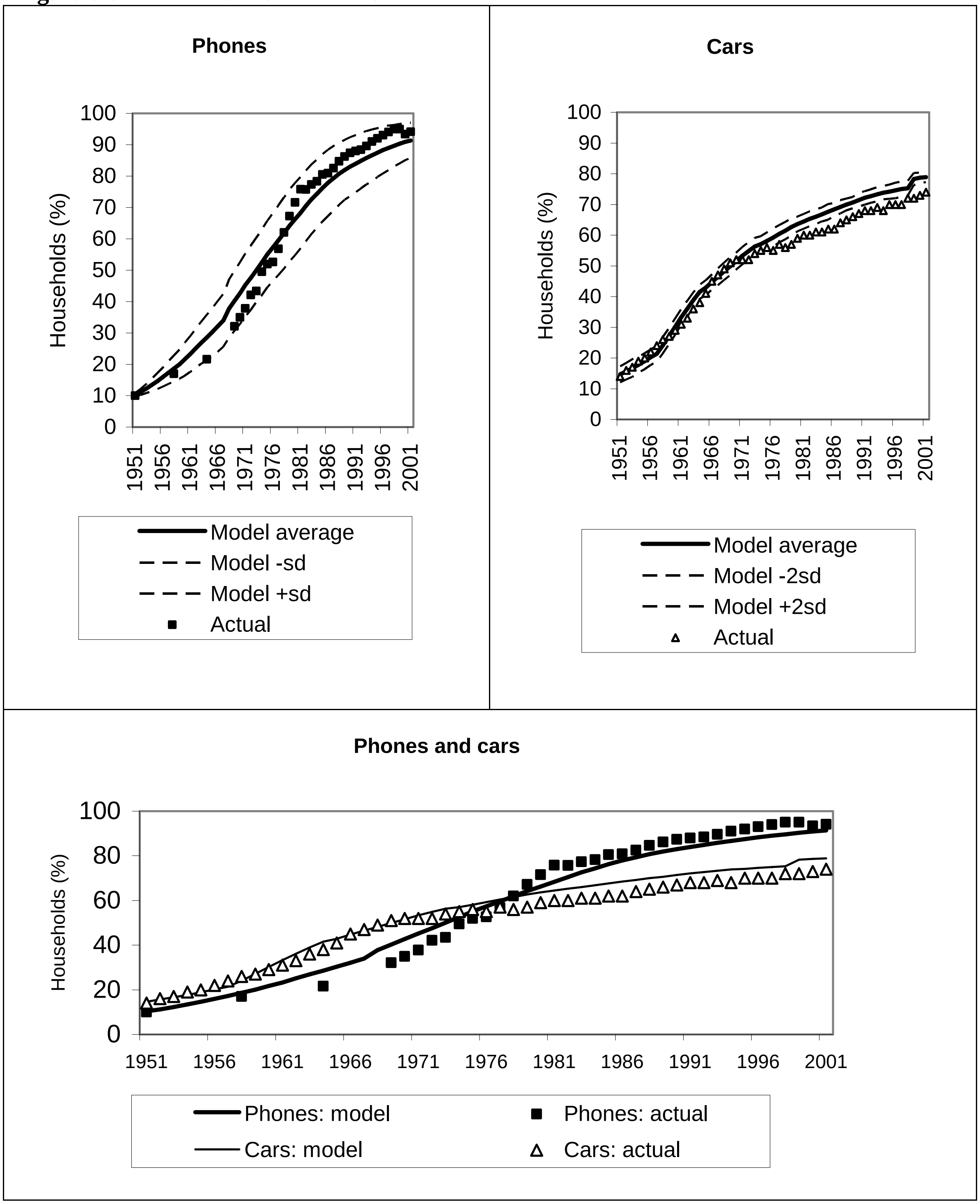


The model broadly replicates the adoption of phones and cars by households from 1951 to 2001 as shown in Fig. 7.5.2.

- The model slightly overestimates the adoption of phones until 1978. This overestimation was expected given the waiting lists that in the early 1950s exceeded 2 percent of business and residential phones. However, the waiting list problem does not explain all the overestimate, which averaged 5 percent between 1969 and 1977. Nor is it clear why there is a slight underestimation thereafter, averaging 4 percent. The model was not expected to reproduce the decline in adoption rate in the last two years as no attempt was made to model the impact of the introduction of mobile phones.
- The model accurately tracks the spread of cars up until the early 1970s but overestimates thereafter. There is little variation around the mean because in the model car adoption is determined by economics and demographics with little scope for stochastic variation. (Because adoption is determined only by income, the apparent jump in the adoption of cars between 1998 and 1999 reflects the relationship between the assumed income thresholds for the purchase and sale of cars and the model's distribution of income. The jump is due to an increase in the proportion of those in class DE with cars.)
- The model shows the adoption of phones overtaking the adoption of cars in 1978 when the adoption of both reached 62 percent: in fact, this event occurred a year earlier, in 1977, and at the lower rate of 57 percent.

The remainder of this Section looks at the extent to which the model reproduces other aspects of phone and car adoption and then reports sensitivity analysis.

Fig. 7.5.2: Model results: base case.

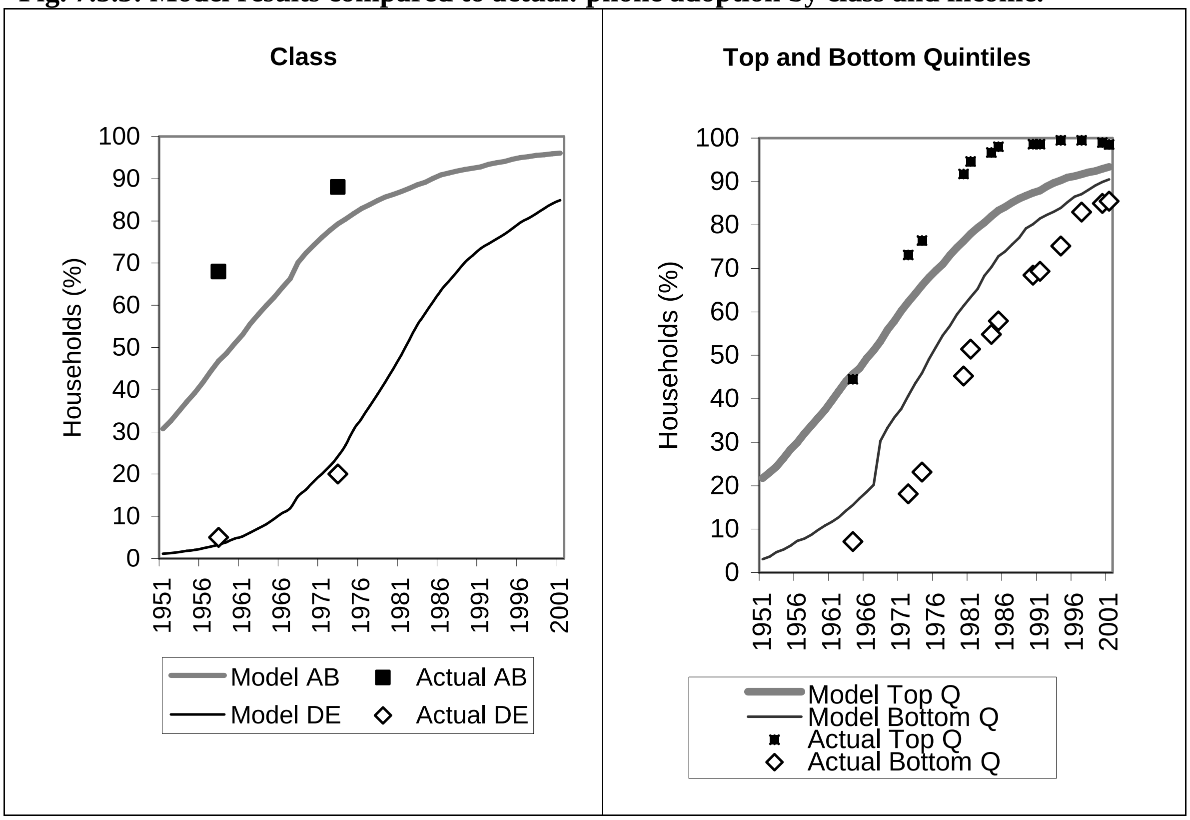


Source: actuals – see Fig 7.1.3.

Adoption of phones by class and income

The adoption process in the model results in about a third of ABs having phones initially, with only 1 in 20 Cs and 1 in a hundred DEs. (Restricting the initial distribution to ABs results in a slightly higher total adoption rate throughout the period.) The model tends to underestimate phone adoption by higher class and higher income households but overestimate adoption by lower income households, as shown in Fig. 7.5.3.

Fig. 7.5.3: Model results compared to actual: phone adoption by class and income.



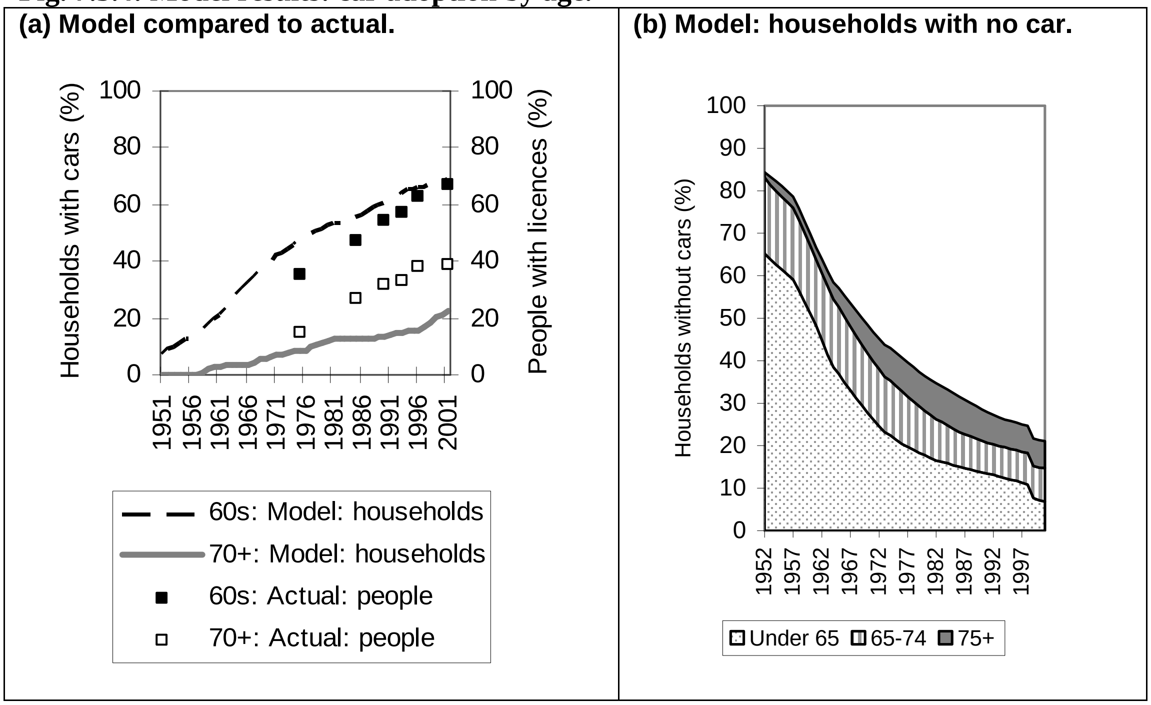
Sources: actuals:
- class: Douglas & Isherwood (1979, p.100)
- income; Ministry of Labour (1965); DE (1975 & 1986); CSO (1995), ONS (2002).

It is, however, not surprising given the assumed diffusion process, that, according to the model, nearly half of those without phones in 2001 were in class DE although this group accounted for only a quarter of the households: there were virtually no ABs without phones.

Adoption of cars by age and class

Although the model tends to over-estimate the proportion of all households with cars from the early 1970s, it tends to underestimate the proportion of over-70s with cars based on licence data, which is not exactly comparable (Fig. 7.5.4).

Fig. 7.5.4: Model results: car adoption by age.



Source: Actuals: DfT(2006a, Table 9.16)

However, the model broadly reproduces the differences in car adoption by class in the mid-1980s (Table 7.5.1). According to the model, while the main reason that households did not have cars in the 1950s and 1960s was affordability, more recently age appears to have been the dominant factor, reflecting both affordability and incapacity.

Table 7.5.1: Model results: car adoption by class: 1985/6.

Percent of households

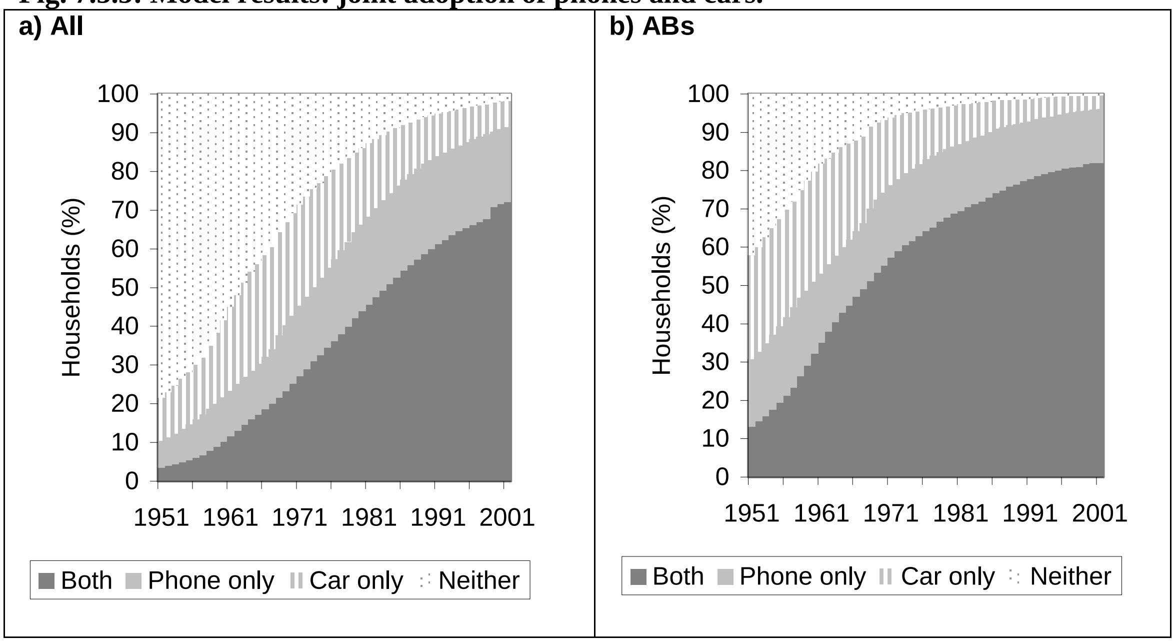
Actual		Model	
Professional/managerial	86	ABs	81
Clerical	54		
Skilled manual	68	Cs	68
Semi-skilled or non-skilled manual	38	DEs	55
Other	31		
All	62	All	68

Source: Actuals: DTp (1988)

Adoption of both phones and cars

The key theme of this thesis is that communications and travel have grown together. Fig 7.5.5 shows how the joint adoption of phones and cars grew in the model. According to the model, in 1951 only 4 percent of households had both cars and phones and four-fifths had neither. By 1984, half of all households had both; and by 2001, seven out of ten households had both and only 2 percent had neither. Half of AB households had both by 1968.

Fig. 7.5.5: Model results: joint adoption of phones and cars.

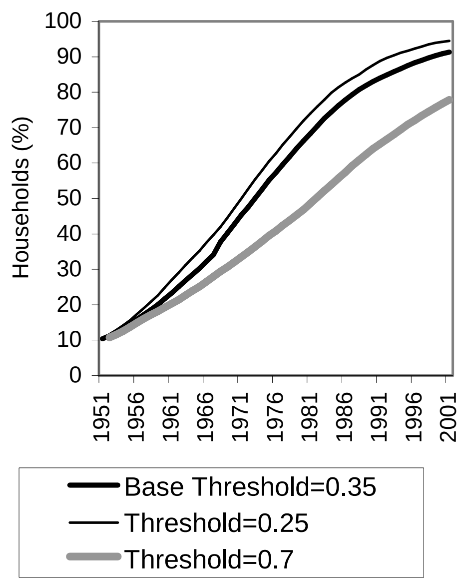


According to the model, initially one-third of households with phones also had cars compared to one-eighth of those who did not have phones. By 2001 those 10 percent of households without phones were, perhaps a little surprisingly, just as likely to have cars as those with phones.

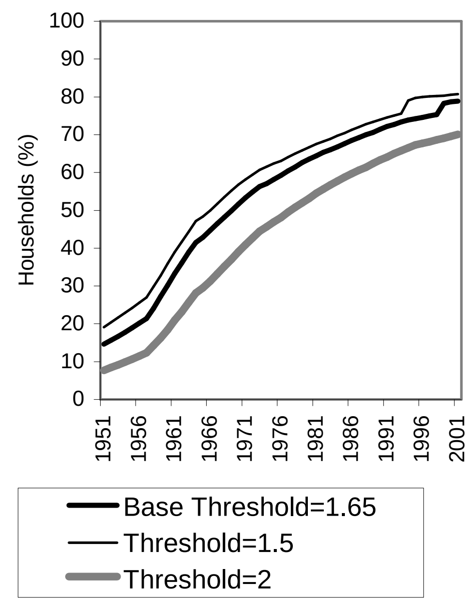
Sensitivity analysis: income threshold

Doubling the income threshold significantly reduces the take-up of phones, and the impact increases over time because of the cumulative network effect assumed in the model: the fewer households there are with phones, the fewer can influence others to adopt. In contrast, changing the income threshold affects the adoption of cars equally throughout the period as there is no network effect. The results are shown in Fig. 7.5.6.

Fig. 7.5.6: Model results: phone and car adoption: effect of changing the income thresholds.



Phones



Cars

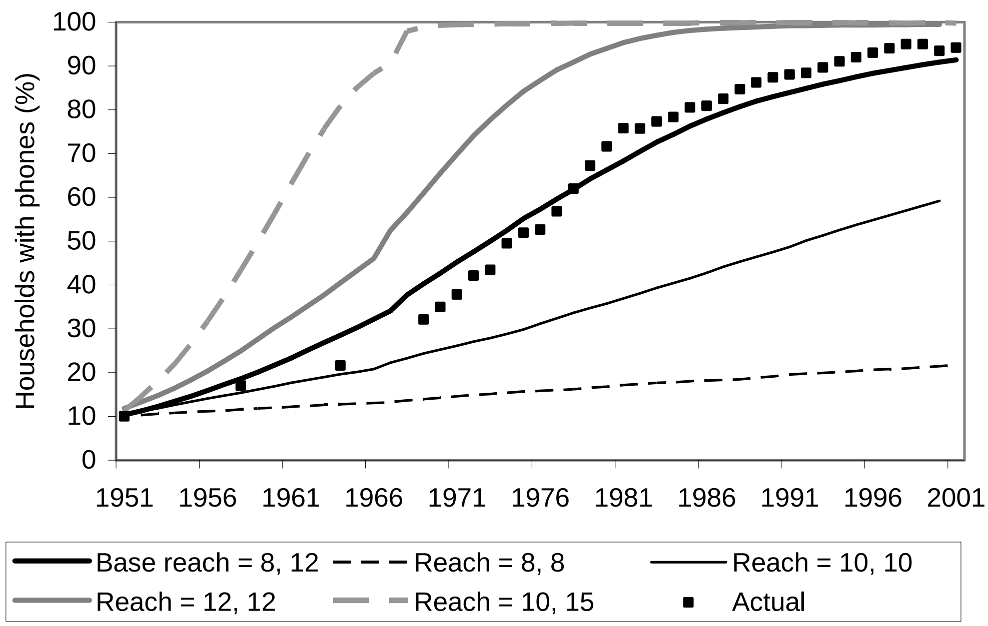
Sensitivity analysis: social reach

The adoption of phones predicted by the model is very sensitive to the assumptions about social reach, which determines the size of personal network. In the base case, the social reach was set at 8 for one-person households and 12 for multi-person households, giving average personal networks of 2 and 4½ respectively. (Details in Fig. 7.5.1 above.) Fig.7.5.7 shows the effect of alternative assumptions. These results suggest that phones spread through close contacts. For instance:

- using social reaches of 10 or 15, implying personal network sizes averaging 3 or 7 respectively, gives a much faster spread of adoption than was observed;
- assuming a reach of 8 for multi-person households produce a much slower spread.

(The assumptions about social reach do not affect the adoption of cars in this model.)

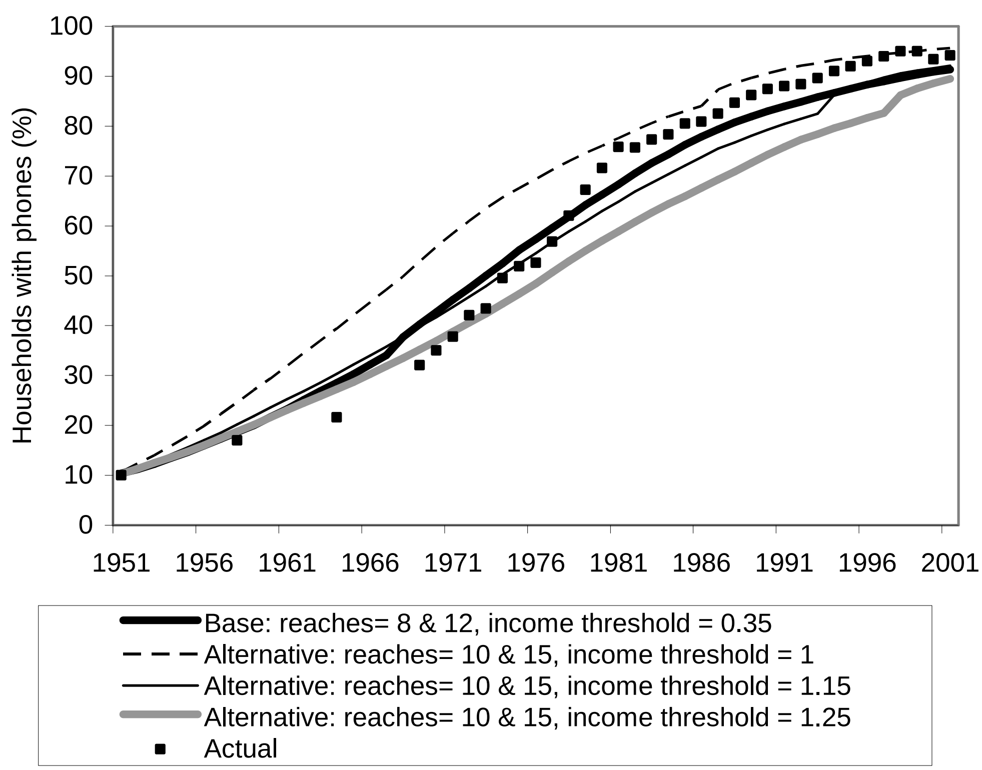
Fig. 7.5.7: Model results: sensitivity of phone adoption to social reach assumptions.



Sensitivity analysis: social reach and income threshold

As shown, increasing the social reach results in faster adoption. But increasing the income threshold for phones at the same time would offset this effect by reducing the adoption of poorer households and, together, these assumptions may give an overall better fit. However, this does not appear to be the case as shown in Fig. 7.5.8 (and confirmed by comparing the fits using ordinary least squares). Setting the one-person household reach at 10 and the multi-person household reach at 15 while raising the income threshold to 1, 1.15 or 1.25 does not produce a better overall fit than the base case. Thus the combination of a low income threshold and low social reaches used in the base case better replicates the data.

Fig. 7.5.8: Model results: phone adoption with higher social reach and higher income threshold.

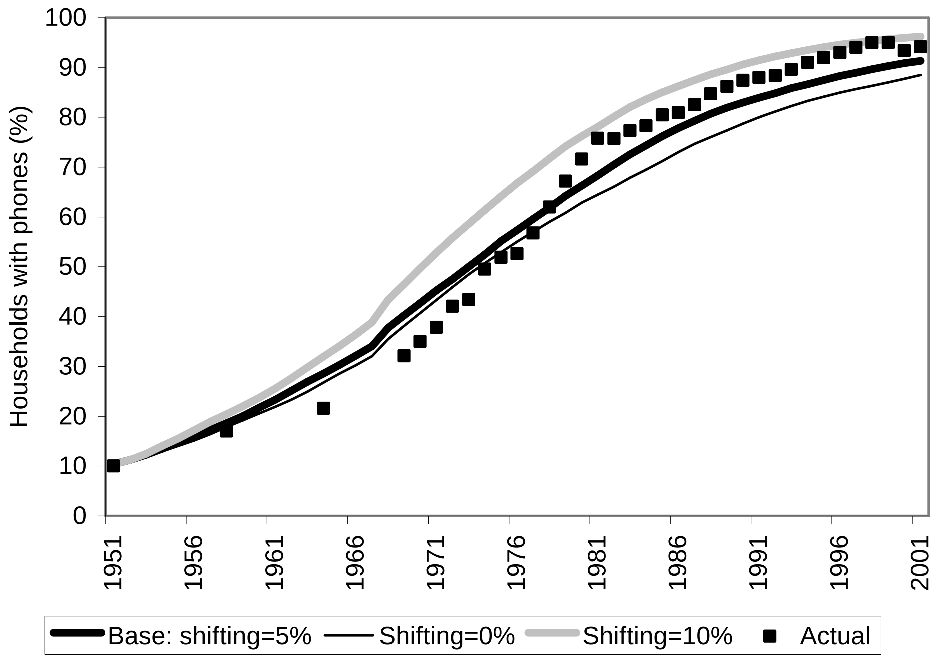


Source: actuals: see Fig. 7.1.3.

Sensitivity analysis: socialshifting

The base case assumes socialshifting of 5 percent a year. Fig. 7.5.9 shows that assuming, unrealistically, no socialshifting gives a slightly better fit for the earlier years. And assuming 10 percent 'shift' each year increases the over-estimate of phone adoption in the early years, but gives a better fit from the 1980s. Overall, the base case scores better on ordinary least squares than either alternative assumption. (Changing the socialshifting assumption does not affect car adoption in this model.)

Fig. 7.5.9: Model results: phone adoption with different social shifting assumptions.

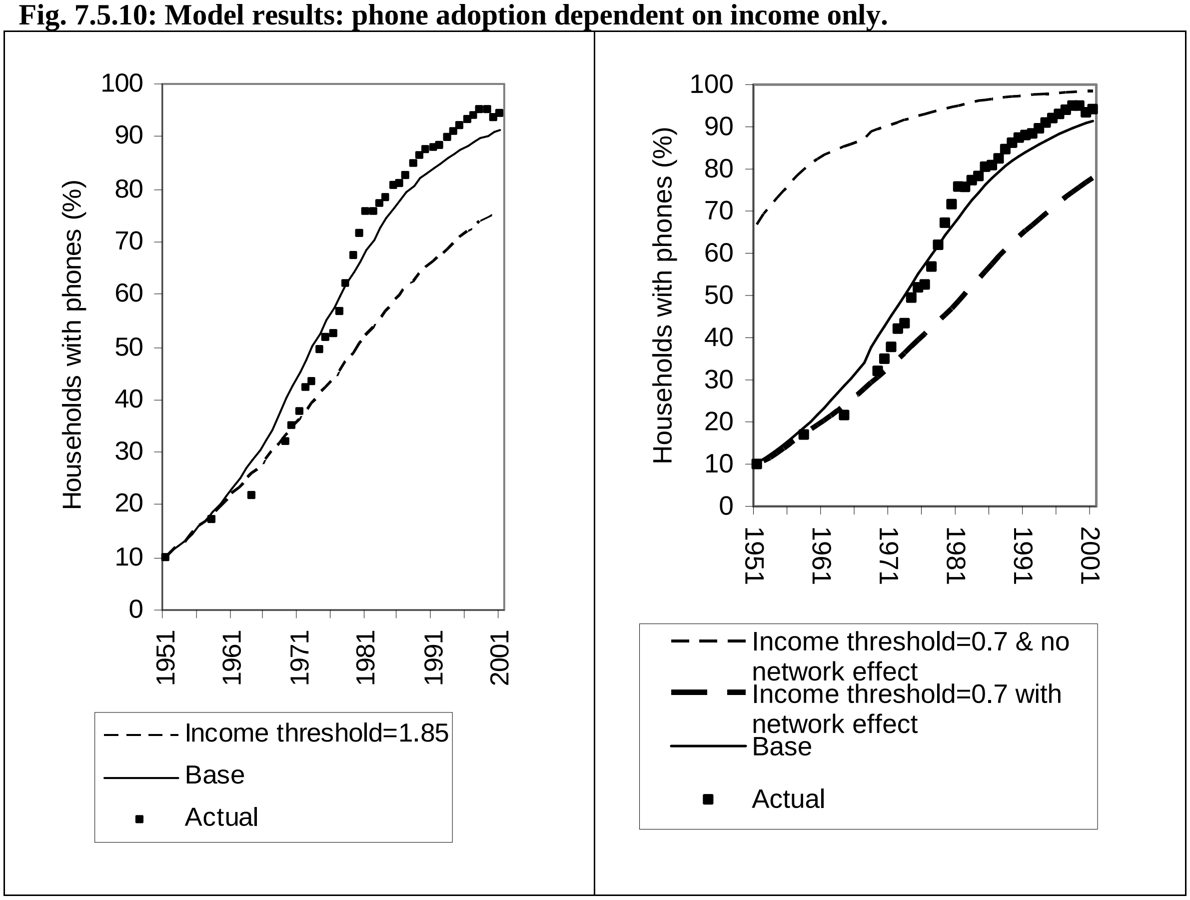


Source: actuals: see Fig. 7.1.3.

Phone adoption: an income based model

A final check on whether the social network model represents a valid hypothesis is to see what pattern of phone adoption the model would have predicted had the same approach been used as for cars. Car adoption has been assumed to be totally dependent on income, with no network effect. To obtain an initial distribution of 10 percent of households with phones, the income threshold would have to be set at 1.85. But as shown in the left hand panel of Fig. 7.5.10, this would have resulted in significant underestimation of phone adoption from the 1970s. Alternatively, had the threshold been set at just 0.35, as in the base case, all households would have had phones by 1968 when in fact only 29 percent did. The right hand panel of Fig. 7.5.10 compares the model's prediction with an income threshold of 0.7, both with and without the network effect, and shows that neither assumptions reproduce the diffusion pattern well. Thus the network effect does seem to have been important.

Fig. 7.5.10: Model results: phone adoption dependent on income only.



Source: actuals: see Fig. 7.1.3

7.6 Use of Phones

Use has not been modelled because of lack of data on phone use for the latter part of the period and because most car use has not been for social purposes (as explained earlier). However, this Section discusses the use of phones and cars following the structure set out in Chapter 5: the social solidarity effect, communication substitution effect, new practices and the global village effect plus the three travel related effects: the complementary travel effect, the travel communications effect and the travel substitution effect.

Communication substitution

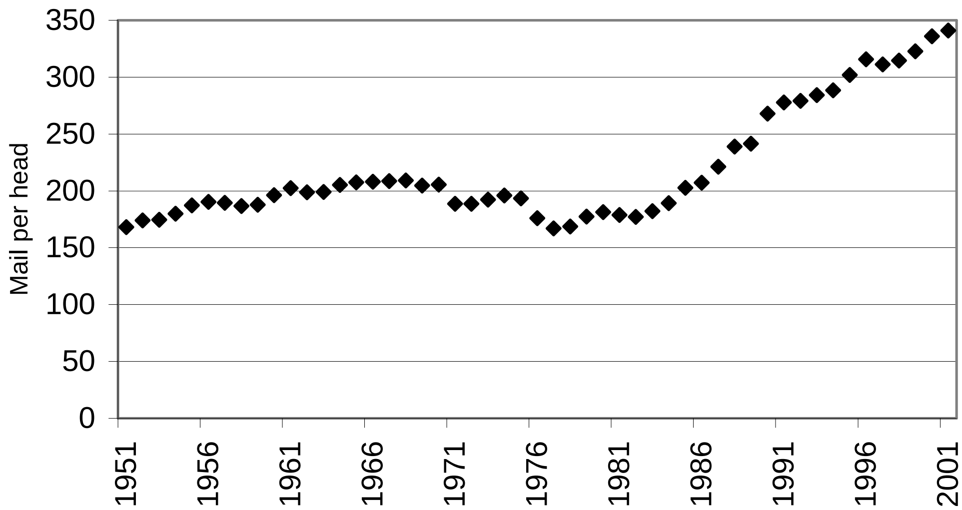
Fischer (1992, p.253) suggested that in the US the phone displaced telegrams and hand-delivered notes. In Britain, phone calls seem to have replaced mail. For example:

- "The City businessman who wished to inform his wife that he would be late for dinner could in 1914 send a letter; in the 1930s he could telephone" (Daunton, 1985, p.49).
- "Since the interwar period, there has been a decrease in personal letters which have to a considerable extent been replaced by the telephone" (Daunton, 1985, p.79).
- In 1999 a survey found that only a quarter would prefer to reply to a letter by letter: half would prefer to phone (Harper et al, 1999, Table 5).

Nevertheless, despite the spread of phones, mail continued to grow. From the 1920s, the mail figures include not only letters and cards, but also newspapers and packets, so it is not comparable with the series used in Chapter 6. On this new basis, between 1951 and the mid-1970s, mail per head stayed fairly constant but since then has grown at about 3 percent a year to reach 340 items a year by 2001 as shown in Fig. 7.6.1. However, much of this growth was due to business mail. Following a review in 1977, the Post Office aimed to increase the volume of mail and between 1975 and 1983, "direct mail grew by 101 percent" (Daunton, 1985, pp.353-4). Thus by 2006, when items per head exceeded 400 a year, only 10 percent of mail was between households, the rest being sent to or from businesses (Postcomm, 2009). It is likely that this personal mail is mostly cards. The

BBC (2006) claimed that each person in the UK sends an average of 55 cards a year, including Christmas cards and postcards.

Fig. 7.6.1: Mail per head: UK: 1951-2001.



Sources: Mitchell (1988); Root (2000, p.445); CSO (1992b, Table 10.37); ONS (2003b, Table 14.31); ONS (2007b, Table 15.31).

Social solidarity and the global village effects

The model presented in the last Section implies that phones were used to communicate with those in existing personal networks, thereby enhancing social solidarity. In 1880, *Scientific American* (cited by Marvin, 1988, p.65) foresaw that the telephone would result in “a new organisation of society” in which “every individual, however secluded, will have at call every other individual in the community” resulting in saving of time and avoidance of all kinds of “annoyances”. Fischer (1992, pp.262-263) argued that “Americans – notably women – used it to chat more often with neighbors, friends and relatives” and “used home telephones to widen and deepen existing social patterns rather than to alter them”. So he concluded that “on the whole, telephone calling solidified and deepened social relations” and increased local contacts (ibid, p.266). Overall, Fischer (ibid, p.253) suggested the phone led to “more social conversations with more people than before” and reported that in:

> "studies done in the United States, Britain and Chile, people with telephones reported more social contacts than those without telephones: subscribers visited and wrote letters more often than non-subscribers. These correlations support the claim that telephone use multiplies all forms of contact" (ibid, p.238).

Fischer (1992, pp.262-263) noted that in the US long distance calling was initially rare. In Britain in the 1950s, less than 10 percent of inland calls were trunk calls and even by 1980 (when the data series ended) only 16 percent were trunk calls (Mitchell, 1988). More recently Smoreda & Thomas (2001) reported that "about three out of four telephone calls are sent to receivers in the same region". However, as noted in Chapter 5, phone calls tend to be longer but less frequent as distance increases.

Fischer noted that (1992, p.25) in their 1933 study, Willey and Rice had reported that phones were used "to augment local ties much more than extralocal ones" and suggested that phones might encourage local activity while cars encouraged "extralocal" activity (1992, p.206). He concluded that "It is difficult to disentangle the expansion of telephony from that of automobility, since both technologies spread almost steadily in the half-century". While Fischer was taking about the US in the first half of the twentieth century, the same could be said of the UK in the second half of the century.

While phones enable people to stay in touch, they do not enable new links to be made: "Americans did not forge new links with strange and faraway people" (1992, pp.262-263).

Complementary travel and travel substitution

Wellman and Tindall (1993) noted a positive correlation between travel and communication with respect to fixed line phones:

> "When we hold constant the strength of the tie, the residential distance, and the role type, we find that people often see those they call often but rarely call those they rarely see….The telephone has helped to transcend the constraints of spatial separation but only in conjunction with the automobile"

Fischer (1992, p.253) suggested that the phone displaced casual drop-in visits but whether these were journeys specifically made for that purpose or were 'just passing' visits is not clear. More recently, Mokhtarian & Salomon (2002, p.163) reported two French studies:

- using data from 1984, Claisse & Rowe (1993) estimated that residential phones generated trips "3-5% of the time, and replaced trips 21-27% of the time" giving "a net substitution impact of 17-22%". However, the trips might have been for other than social purposes, such as shopping.
- using data from 1994, Massot (1997) found greater mobility associated with greater use of phones, i.e. complementarity.

Travel communications effect

Conversely, travel promoted communications. Fischer (1992 p253) noted how fixed line phones were used to arrange meetings. More recently, in a study of phone use in Britain in the late 1990s respondents "reported making more frequent calls to those people they saw on a regular basis and this was usually to check or make arrangements" (Lacohee & Anderson, 2001).

7.7 Discussion and Conclusion

As in Chapter 6, it is the potential for communication and travel that is examined and the modelling has not taken into account detailed changes which would increase its complexity. The basis of the model is a replication of key changes in household structure and economic conditions.

- The key demographic changes are the increase in the proportion of one-person households and the reduction in the proportion of middle-aged households.
- The key economic changes are the rise in real incomes combined with a falling economic activity rates and a fall in the cost of motoring in the first part of the period.

The model also simplifies by ignoring the availability of call boxes and motorbikes.

This model is closer to a detailed evidence-based model than a more general, abstract model. This model differs in important respects from that presented in Chapter 6:

- it is based on households rather than individuals;
- it models adoption rather than use;
- it allows agents' economic status to change over time;
- it uses social class directly as a key factor rather than using income;
- it does not specifically incorporate migration;

Table 7.7.1 summarises the model.

Table 7.7.1: Summary of the model.

Target	Adoption of phones and cars: 1951-2001	
Agents	Households	
Agents		
	Attributes	Dynamics
Location	Grouped by social class	
Demographic	Type Size Age	 Marriage, divorce & widowed 'Birth' and 'death'
Socio-economic	Class Employment status Income	 Unemployment, sickness, retirement Changes with employment status Grows at 2% pa.
Personal networks	Social reach = 8 or 12	Socialshifting

Having reproduced key demographic and economic changes, the model then applies two separate models of diffusion, one for phones and one for cars. The spread of adoption for cars depends only on economic growth and the fall in the relative price of motoring. In contrast, the spread of phones depends very little on affordability but rather on personal networks, social class and mobility. This reflects the fact that there is little point having a phone if your friends and family do not have them and that, compared to cars, phones are relatively inexpensive. The model assumes that phones were adopted first by the upper and middle classes, both reflecting and arguably increasing, their geographical mobility. It also assumes that each household influenced only a very few other households, reflecting the fact that phones are used for regular contact with a few important people. On this basis, the model broadly reproduced the observed pattern of phone adoption between 1951 and 2001. Various sensitivity tests, including using an income-based diffusion model for phones, confirm that the selected parameter values fit the observed data better than alternative values. The model demonstrates how the physical phone network can be created by the social network. Both the model and other evidence suggest that phones are used for social purposes and that their adoption and use is related to class and mobility.

Despite their relatively high cost, cars were initially more popular than phones. Kellerman (2006, p.121) noted that the adoption of phones surpassed that of cars at around the 60 percent level in the UK, France, Germany and the US. This phenomenon can be explained by the fact that the adoption of cars is naturally constrained by affordability and ability to drive, whereas there are no such constraints for phones. The adoption curve for cars does not therefore follow the classic S-curve, with adoption eventually approaching saturation. Indeed, car adoption, as measured by the percentage of households with at least one car, has probably reached saturation in Britain. The recent increase in the number of cars is due rather to second (and third) cars in households. It is therefore inevitable that the adoption of phones overtakes that of cars.

Table 7.7.2 summarises the results.

Table 7.7.2: Summary of the results.

Target	Phone and car adoption: 1951-2001	
Adoption		
Key factors	Phones: personal networks & income Cars: income	
Use		
Communication effects		
Social solidarity?	Yes	Strong
Communication substitution?	Yes	Strong
New practices?	Yes	
‘Global village’:		
- maintain contact?	Yes	
- new friends?	No	
Travel effects		
- Complementary increase?	Yes	
- Travel communications?	Yes	
- Substitution reduction?	Yes	Limited

This Chapter has presented a model of the adoption of phones and cars in the second half of the twentieth century. The model replicates key demographic and economic changes. It was assumed that phones diffused across households through personal networks starting with the upper and middle classes. For cars diffusion was determined solely by income growth. Other evidence confirms the view that domestic phones are used for social purposes, to keep in touch with existing contacts. Although the model was run to 2001, no account was taken of the arrival of digital communications in homes in the late 1990s. This revolution is discussed in the next Chapter.

Chapter 8: Mobiles and the Internet

Chapter 6 investigated mail and rail and Chapter 7, phones and cars. So it would seem a natural progression for Chapter 8 to look at the internet and air or international travel. Air and international travel have certainly increased and the internet has played an important role in marketing cheap flights. The number of overseas trips taken by UK residents increased from almost 50 million in 1998 to almost 70 million in 2007, due to the increase in travel by air (DTp, 1996; DfT, 2006a; DfT, 2008). But most travel is not for social reasons, as noted in Chapter 7 for travel within the UK. In 2007, only 19 percent of UK international air passengers travelled to visit friends and relatives (CAA, 2009, p.19). The majority of trips were for business or holidays. But the focus of this study is on social networks, not on business travel or tourism: it is about people travelling to meet other people whom they already know rather than to meet strangers or to look at foreign places. Within the UK, the average distance travelled per person increased by only 2 percent between 1995/7 and 2006 but the average distance travelled per trip rose by 7 percent (DfT, 2008, Table 1.3). This is consistent with more geographically spread personal networks, although of course, as noted in Chapter 7, social journeys form only a small part of total journeys. So this Chapter focuses on the potential for travel rather than the growth in use of any particular mode.

Furthermore, the digital revolution is not just about the internet, but also about mobiles – phones and ‘smartphones’, such as *Blackberrys* and *iPhones* (Ofcom, 2009b, p.208). The two modes of communication are related, not just in their underlying digital technology but also because both are, in different ways, related to fixed line phones: mobiles can be used to make voice calls to fixed line phones; and fixed line phones, and increasingly mobiles, can be used to make internet connections.

This Chapter presents a model of the adoption and use of mobiles and the internet drawing on work presented in earlier Chapters:

- the social circles model presented in Chapter 4;
- the general model described Chapter 5;
- the demographic modelling and the importance of literacy from Chapter 6 and
- the modelling of class from Chapter 7.

Section 1 briefly sets out the history of mobiles and the use of the internet for communications. Section 2 presents a model of adoption of both mobiles and the internet to 2007, and Section 3 extends it to cover their use and the impact on travel. Section 4 uses the model to look ahead to 2016 and 2021. Section 5 concludes with a discussion of the results of the model, and the implications for the wider debates about the use of this technology. (The diagrams are colour coded: blue for mobiles, red for the internet.)

Most of the data comes from Ofcom, the Mobile Data Association (a UK industry body) and the ONS.

8.1 History

Mobile phones

The basics of mobile communications were established in the nineteenth century (Crookes, 1892; Huurdemann, 2003, p.208; Goggin, 2006, p.24). In 1901, Ayrton foresaw

> "a time when if a person wanted to call to a friend he knew not where, he would call in a loud, electromagnetic voice, heard by him who had the electromagnetic ear, silent to him who had it not. 'Where are you?' he would say. A small reply would come, 'I am at the bottom of a coal mine, or crossing the Andes, or in the middle of the Pacific.'."

The first basic "Mobile Telephone Service" was launched in the US in 1946 and in Europe, in Sweden, in 1955 (Huurdemann, 2003, p.519; Goggin, 2006 p.25; Agar, J., 2003, p.49). However, with this early technology, the number of users was limited: thus, for example, by 1981, there were only 20,000 mobile users in Sweden (Agar, J., 2003 p.49). This limitation was overcome by the invention of a cellular system, with the first public service launched in Japan in 1979 (Huurdeman, 2003, p.520; Goggin, 2006, p.29). Initially it was assumed that portable phones would be confined to cars and even in 1989 what was claimed to be "the smallest and lightest" phone weighed 11 ounces (Goggin, 2006, p.31).

There have now been three generations of mobile phones:

- First generation (1G), an analogue system offering voice communication only.
- Second generation (2G, such as GSM), a digital system offering better transmission quality and security plus many other features such as texting (or formally, short message service (SMS)), voicemail, address books and subscriber identity module (SIM) cards, allowing data to be transferred between phones. More advanced handsets offering limited multimedia services and access to the internet became known as 2.5G or GPRS (General Packet Radio Service).

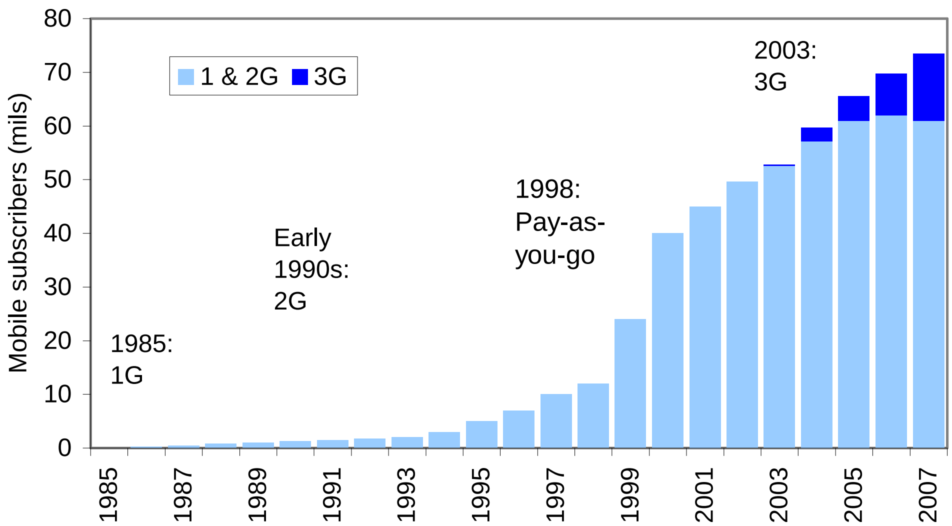
- Third generation (3G, such as UMTS (Universal Mobile Telecommunications System)), again digital, offers internet connectivity and “interactive video communications”.

(Goggin, 2006, pp.31-3; Ofcom, 2009b, pp.321, 324).

Mobile phones were adopted far faster than anticipated. In the 1980s, planning for GSM, a 2G technology, “had been based on 10 million subscribers all over Europe, North Africa and the Middle East by the end of the century” (Huurdemann, 2003, p.530). By July 2009, there were 3.9 billion GSM subscribers worldwide (GSM Association, 2009). Huurdeman (2003, p.525) argued that it was the introduction of pre-paid service, first introduced in Germany in 1995, “which made cellular radio worldwide a mass consumer product”. “When government regulations, technological standards, and business pricing systems favor the diffusion of wireless communication, it becomes explosive” (Castells et al, 2007, p.252). A key point is that mobile phones can be used to communicate with fixed line phones, whereas when fixed-line phones were introduced there was little point in having one unless your friends and family also had one.

As with fixed-line phones, royalty were in the vanguard of adoption in the UK: the Duke of Edinburgh had a radio car phone in 1954 (Agar, J., 2003, pp.72-74). However, it was not until 1985 that the first mobile phone network was introduced in the UK. Second generation digital mobiles were launched in the early 1990s (Department of Trade and Industry (DTI), 1997, p.1) and the third generation arrived in the UK in 2003 (Ofcom, 2008b, p.320). As elsewhere, this growth was not foreseen: in 1997 it was predicted that “around 30% of the UK population – perhaps approaching 20 million people – will be regular users of a mobile phone in the early years of the next century” (DTI, 1997, Foreword). It was double that: by 2001, 73 percent of adults had mobiles (Oftel, 2001b, p15). Fig. 8.1.1 shows the growth in the number of SIM cards, the measure used by the industry to count subscribers. Since 2004-5, this figure has exceeded the population. By spring 2008, there were 75 million SIM cards although ‘only’ 49 million people used mobiles, the 26 million difference being due to inactive and rarely used mobiles plus some 9 million people with more than one SIM card (Ofcom, 2008b, pp.293, 334-5).

Fig. 8.1.1: Estimated number of mobile phone subscribers: 1985-2007.



Sources: Ofcom (2004 & 2008b, pp.309 & 320) See also: Huurdeman (2003, p.524), Goggin (2006, p.29) & DTI (1997, p.1).

Rogers (2003, pp.259-263) suggested that mobile phones were adopted so quickly because they scored well against each of these criteria:

- Relative advantage:
  - mobiles offered time savings – re-arrangement of meetings and use of otherwise dead time;
  - status in the early days and
  - later, financial benefits as costs fell.
- Compatibility:
  - mobiles connect with the existing fixed line network so there was no need for a critical mass to be attained
  - mobiles could be personalised, for example, by ring tone.
- Complexity:
  - Rogers argued that mobiles are used just like a regular phone, which is true in that people were familiar with the concept of a phone, and making voice calls is straightforward. But it is not true of the many other features. Indeed, one of the reasons given by late adopters for not adopting sooner was the complexity of the devices. (Rogers, 2003, pp.294-5).

  - Rogers argued that texting is an example of what he calls 're-invention' i.e. people can adapt the device to their own uses.
- 'Trialability': they were easy to try out by borrowing from friends.
- Observability: mobiles were both highly visible and audible.

The Internet

The internet grew out of the US Government's ARPANET project in the 1960s and the World Wide Web emerged in 1992, with text, images, sound and documents linked by hypertext. (For a fuller history, see for example, Kitchen (1998, pp.28-41) and Connected Earth (2009).) The speed of the spread of the internet is unprecedented:

> "To reach 50 million subscribers took the telephone close to 75 years, the radio 38 years, the TV 13 years and the internet less than four years from the introduction of the WWW in 1992" (Huurdeman, 2003, p.587).

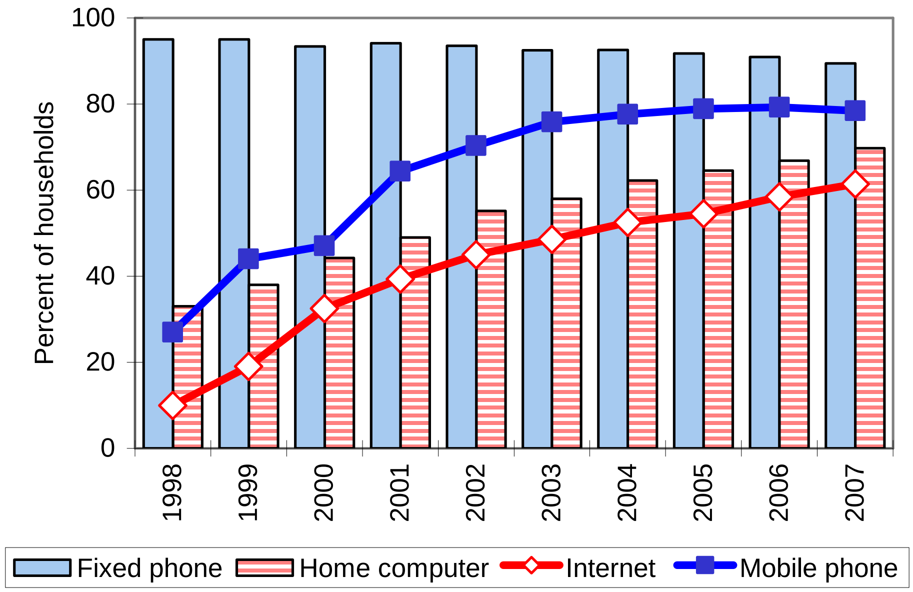
By 2000, the internet had spread to almost every country in the world with an estimated 315 million users, albeit concentrated in the developed world (Huurdeman, 2003, pp.589-92).

Domestic access to the internet requires both a phone or cable connection and a computer. (Although some mobile devices can be used to access the internet, the speeds are significantly lower, as is discussed later.) In the UK, by 1990, 87 percent of households had fixed line phones and 17 percent already had computers, which could then be used for communication, albeit by creating paper-based letters (ONS, 2008d). The arrival of the internet turned the household PC into a networked communication device and gave an impetus to the demand for computers at home.

Digital adoption in the UK

The proportion of UK households with fixed line phones peaked in 1999 and by 2007 had fallen back to the level of the early 1990s (Fig. 8.1.2). Consistent and reliable data on internet access is available from 1998 when 10 percent of households were online; at that time about a quarter had a mobile phone.

Fig. 8.1.2: Households with fixed and mobile phones, home computers and internet access: 1998-2007.



Source: ONS (2008a, Table A51).

By 2007, 8 out of 10 households had mobiles and 6 out of 10 had internet connections (Fig. 8.1.2). (Dutton et al (2009, p.7) claimed that 70 per of households had internet access by 2009.) Furthermore, in 2008, 10 percent of households without an internet connection at home accessed it from elsewhere (ONS, 2008d) but Dutton et al (2009, p.8) claimed that “internet use and home access” were “nearly equivalent”. It is arguable that use of the internet for social purposes is most likely to be concentrated among those who access the internet from home.

Since 2005, one in 10 adults have reported living in households with a mobile but no fixed line phone, rising to one in 5 among younger and lower income groups in urban areas and in DE households (Ofcom, 2009b, p.248; Department for Business, Enterprise & Regulatory Reform (BERR), 2009, p.26; Ofcom, 2008c). Table 8.1.3 shows the latest figures.

Table 8.1.3: Proportion of households with fixed and mobile phones: UK: Q1 2009.

Percent of adults

	Fixed		
Mobile	**Yes**	**No**	**Total**
Yes	80	12	92
No	7	1	8
Total	87	13	100

Source: Ofcom (2009b, p.248).

8.2 Model of Adoption

Stylised Facts

Because there is a long run of annual data from the *Family Spending Surveys*, the target of the adoption model is taken to be the increase in the percentage of households between 1998 and 2007 with:

- mobile phones: 30 percent to 70 percent
- internet connections: 10 percent to 61 percent

(as shown in Fig 8.1.2).

This Section follows the pattern of Chapter 6, starting with demography and then considering availability, affordability, skill and social networks.

Demography

Mobiles are personal in that they provide person-to-person links. Kennedy & Wellman (2007) noted the shift from household to personal transport and communication in that each adult had a car as well as “personalized ICT” and argued that households are “now the hubs of individualized communication networks”. This is consistent with the observed tendency to use mobiles even at home (Ofcom, 2008b, pp.294-6). Ofcom (2008b, p.71) noted that mobile broadband is “likely to be an individual rather than a household purchase”. Therefore, in this model agents represent individuals but have access to household resources.

As agents represented individuals in Chapter 6, the same basic method is used for the demographics here, but over a wider age range to reflect the facts people live longer and children use mobiles and the internet. According to Ofcom (2008b, pp.294, 345) in 2008

- two-thirds of children aged 8 to 11 and 9 out of 10 aged 12 to 15 had access to or owned a mobile and
- 80 percent of children over 11 had access to the internet.

So in this model individuals are aged from aged 10, to, initially, 94 but rising over time to 105. Following Chapter 7, no younger agents die. This replicates the age distribution expected in 2021, slightly understating the proportion of very old. (Details in Box 8.2.1).

Box 8.2.1: Demographics pseudo-code.

Initialisation
Divide the initial population into 8 age bands:
- 10-19: 15%
- 20-29: 14%
- 30-44s: 26%
- 45-59: 22%
- 60-64: 5%
- 65 to 74: 10%
- 75 to 84: 6%
- 85 to 94: 2%

Allocate age to each agent.
Within each age band, age is allocated randomly and uniformly. So, for example, 1.5% of agents will be allocated to each age from 10 to 19.

Execution
Agents age.

Agents die.
No agents under 45 die. Thereafter the mortality rates are set at
- 45-54: 0.3%
- 55-64: 0.8%
- 65-74: 3%
- 75-84: 6%
- 85 and over: 17%
- Agents reaching 105 die.

Calculate total number of deaths and create same number of new agents to maintain a population of constant size.
Set age of new agents to 10.

Results

Percent

Age	2001			2021		
	Actual	Model	(sd)	Forecast	Model	(sd)
10-29	29	29	0.5	27	27	1.0
30-45	26	26	0.6	23	22	0.7
45-59	22	22	0.4	22	23	0.9
60-74	15	15	0.4	18	20	1.1
75+	9	8	0.4	11	9	0.7
Total	100	100		100	100	

Source: Actual and Forecast: ONS (2008e).

Availability

Castells et al (2007, p.257) noted that some of those in less-populated areas of advanced countries do not have access to mobiles. In the UK, it has been claimed since 1997 that 97 percent of the population of the population are covered by mobile networks (DTI, 1997, para 6.9) and that by 2008, 99 percent of the UK population had at least 2G coverage and "over 90%" had 3G coverage (Ofcom, 2008b, pp.107-8). But these 'official' figures exaggerate. A recent survey by the Communications Consumer Panel (2009) found that over a half of consumers reported problems with reception, one third on a regular basis. (For example, although mobile operators say I have 2G coverage at home, which is within 50 miles of London, in fact the signal is too weak for voice calls and texting is difficult.) However, Ofcom (2008c) argued that poor coverage did not affect the take-up of mobiles.

Most people access the internet via fixed phone lines but increasingly cables and mobiles are used. When the internet first arrived in the UK in the mid-1990s, access was by modems that, at best, gave 28.8 kilobytes per second with calls charged at local rates. In 2000 broadband became available for domestic users in the UK (Connected Earth, 2009a), providing much greater speeds at a flat rate price. It is not straightforward to compare broadband speeds, measured in megabits per second (Mbps), and modem speeds that are reported in kilobytes per second. Broadband speeds are often not as high as advertised due to factors such as distance from the local exchange and line quality (ONS, 2009e; Ofcom, 2009d). Nevertheless, broadband is so much faster than modems that it enables activities that were not previously possible over the internet: Di Gennaro & Dutton (2007) argued that it enables users to "better integrate the technology into their everyday lives". The market share of broadband has increased continuously reflecting its "popularity, widespread availability and increasingly competitive connection packages" (ONS, 2009e). By December 2008 95 percent of households in the UK with internet connections had broadband (ibid).

Almost all internet users have a mobile phone (Dutton et al, 2009, p.11; Ofcom, 2008a). The internet can now be accessed from mobile devices, phones, laptops and handhelds. Using laptops seems to be the fastest growing method of mobile access (Ofcom, 2008b, p.300). In early 2008, nearly a quarter of recent adult internet users had used a laptop via a wireless connection: fewer had used a mobile (ONS, 2008d). However, according to Ofcom (2008b, p.300) the introduction of the *iPhone* in July 2008 marked a “step change” in the use of the internet through mobiles. By early 2009, half of those with home access had connected to the internet using a wireless connection (Dutton et al, 2009, p.12).

However, mobiles cannot provide the same the speed of internet access as fixed lines: 3G mobiles provide connection at the maximum rate of 2Mbps with “the effective rate being about 384 kps” (Goggin, 2006, p.203). So although three-quarters of mobile broadband users were using it within the home, only one-third of mobile broadband users claimed it was a substitute for fixed line internet access (Ofcom, 2008b, pp.71 & 302). Dutton et al (2009, pp.4 & 11) found that accessing the internet from wireless and mobiles doubled between 2007 and 2009, by when a third of internet users reported using their mobile to access email or the internet. This trend will be accelerated with the introduction of Long Term Evolution (LTE) technology, which can deliver maximum speeds of 50 Mbps (Department for Business Innovation and Skills (BIS), 2009, p.63). It has been noted in the US that that there was a “strong” increase between 2007 and 2009 in accessing the internet by laptops or mobiles (Horrigan, 2009, p.3) and many think that by 2020, mobiles will be the prime means of connecting to the internet (Anderson & Rainie, 2008, p.5). In the model, both mobiles and the internet are assumed to be available to everyone.

Affordability

Mobiles can be paid for by monthly contracts, with a standing charge plus charges for use, or on a pre-paid, pay-as-you-go (PAYG) basis where there is no standing charge. In the UK, the caller pays. In general, the caller-pays system together with pre-paid PAYG billing encourages adoption (Castells et al¸ 2007, pp.31-34). In the UK the high cost of fixed line phones may also have helped (ibid, p.252). The launch of PAYG in 1998 boosted the UK market (Larsen, 1998; BBC, 1999) as can be seen in Fig. 8.1.1. By 2001, around two-thirds of mobiles were PAYG and this has remained the case (Oftel, 2001b, p.15; Ofcom, 2008b, p.320). Because mobiles were only available on contracts until late 1998, the model assumes that for that year, only those aged 18 and over could adopt.

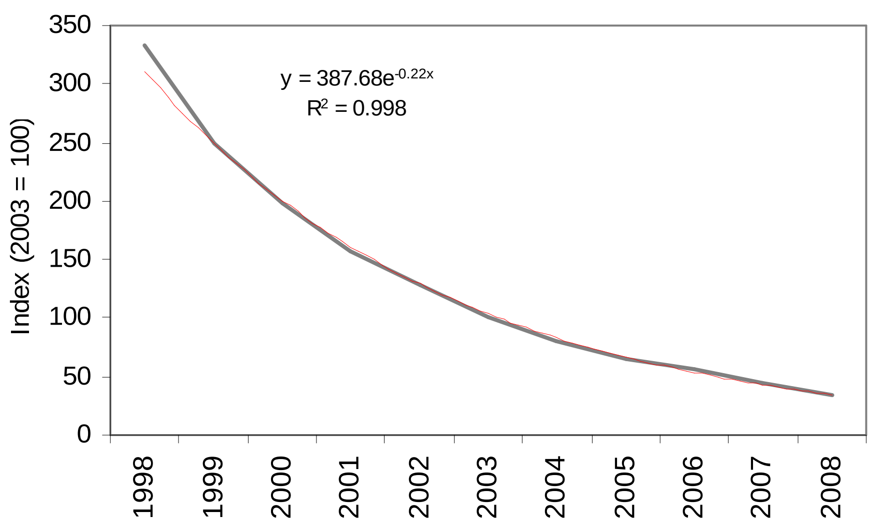
The cost of a mobile is difficult to assess because operators in the UK often subsidise the cost of the handset for those on contracts and because varying amounts of 'free' minutes and texts are included in the packages; indeed, unlimited free texts are "an increasing feature" even for PAYG users (Ofcom, 2008b, p.346). Despite this difficulty, it seems clear that the cost of having and using a mobile has fallen in absolute terms and relative to both fixed line phones and the retail price index (RPI):

- 1996/7 and 2000/01: using a method based on revenue, Oftel (2001 December pp.25-26) reckoned that the "fixed cost" of mobiles fell by almost 90 percent while that of fixed lines did not change at all; the cost of mobile calls fell by 60 percent while the cost of fixed line calls fell by some 40 percent. By comparison, the RPI rose 12 percent.
- 2002 to 2007: using a different method, Ofcom (2008 p.318) reckoned that "the average mobile cost per voice minute" fell from around 14p in 2002, to between 10p for PAYG and 12p for contract users by 2007. Over this period, the RPI rose by 17 percent.

Real household spending on mobile services grew by 30 percent between 2002 and 2007, by which time it accounted for half of household spending on telecommunications on average (Ofcom, 2008b, p.327). Nevertheless, spending on telecommunications accounted for only 3 per cent of household spending, on average. (Ofcom, 2008b, p.327). And even for teenage girls, noted for their high use, expenditure on mobiles accounted for only 7 percent of their budgets in 2002-4 (ONS, 2005b, pp.19-24). This means that even large changes in prices and use have little effect on households' overall spending patterns. However, there is evidence to suggest that children send text messages because of the low cost, although they substitute voice calls when they become young adults (Ofcom, 2008b, pp.343, 346; Castells et al, 2007, pp.154-5).

Measuring price changes of internet access is not only difficult because of the various cost components but also because of the problems that arise when products are changing rapidly as technology develops (see, for example, Brand, 2001). The capital costs of "information processing equipment" have certainly fallen, dramatically if Fig.8.2.1 is to be believed, but computers still cost hundreds of pounds. The running costs comprise payments to Internet Service Providers (ISPs) and the cost of having a fixed line phone, and for dial-up accounts, the cost of phone calls. However, most internet connections are now broadband and the cost of broadband varies considerably; in June 2008 it could be as low as £7.50 per month (Ofcom, 2008b, p.331). Having bought the equipment and paid the broadband subscription, communicating over the internet is free at the point of use.

Fig. 8.2.1: Price of "information processing equipment": 1998-2008.
Consumer expenditure price deflator for "personal computers, printers, calculators, word processors and typewriters" (ONS, 2009c, p.256).

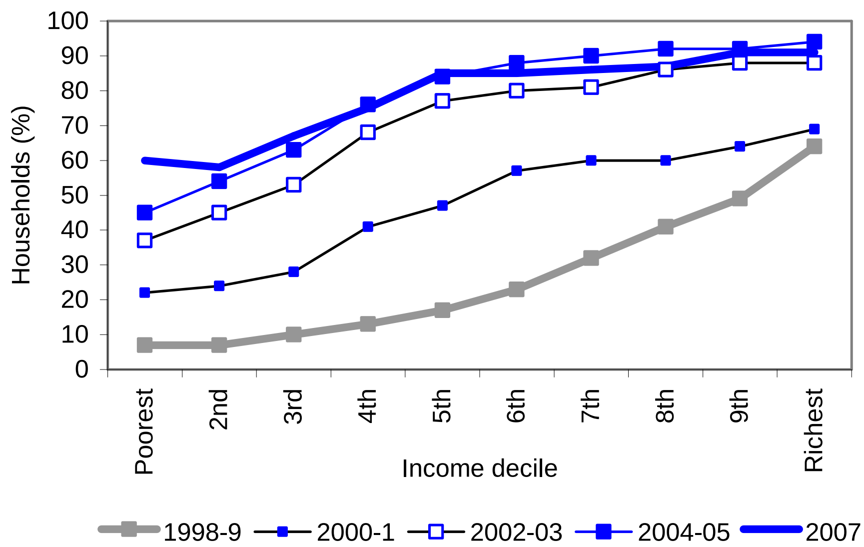


Source: ONS (2009b, series AWNW)

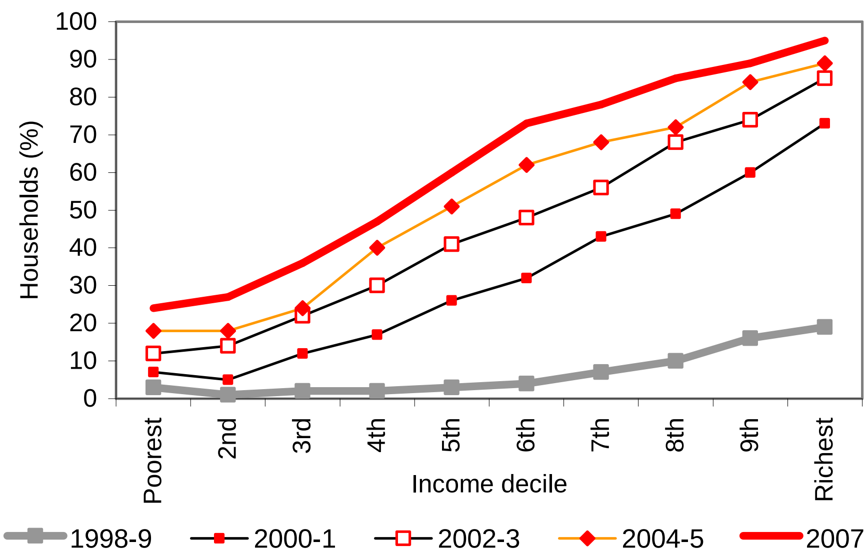
Despite the cost, surveys undertaken between 2000 and 2005, found that only some 8 to 10 percent of adults who had never used the internet attributed this lack of use to costs. More recently, in 2008, about a quarter of households without an internet connection claimed its absence was due to cost: 15 percent blamed equipment costs and 11 percent blamed access costs (ONS, 2008d; BIS, 2009, p.33).

Between 1998 and 2007, real GDP per head rose by 2.4 percent a year (Fig. 2.2.2). Together with falling prices, rising real incomes made mobiles and internet connections more affordable. Fig. 8.2.2 shows how the adoption of mobiles and the internet spread across income groups. For example, in 1998-9, few of the poorest households had either. By 2007, 6 out of 10 of the poorest had mobiles and a quarter had an internet connection.

Fig. 8.2.2: Adoption of mobile phones and internet by income decile: 1998-9 to 2007.
(a) Mobiles



(b) Internet



Sources: ONS (1998,1999,2002,2003a, 2003b, 2005b, 2007d, 2008a).

As in Chapters 6 and 7, affordability is modelled by allocating incomes and drawing an affordability threshold. To reflect household resources, household income is used. A rather simpler methodology is used than in Chapter 7 but still with the aim of producing a Gini coefficient of about a third. Details are in Box 8.2.2.

Box 8.2.2: Modelling income.

Initialisation

As in Chapters 6 and 7, the income figure is an index number. To generate a Gini coefficient of about a third, with an overall average income of 1, a distribution of income is generated for each class using a normal distribution with the following means and variances, based on the data below:

- ABs: mean 1.35, standard deviation 0.6,
- Cs: mean 0.85, standard deviation 0.4,
- DEs: mean 0.7, standard deviation 0.35.

Half are assumed to have working partners who on average boost the income by a quarter.

No allowance is made for unemployment, sickness or early retirement.

Income is halved for those aged 65 and over.
Minimum income: 0.25.

Execution

To allow for fluctuations in income, 10% of households with incomes below the threshold are allowed to adopt mobiles, and 5%, PCs.

All are assumed to retire at 65, when incomes halve.

Income growth is assumed to be 2.4% a year.

Skills

UNESCO (2009) defined as ‘functionally literate’ a person

> “who can engage in all those activities in which literacy is required for effective function of his or her group and community and also for enabling him or her to continue to use reading, writing and calculation for his or her own and the community’s development.”

In literature about developing countries, this concept of literacy is applied to the ability to use digital communication technology (e.g. Chipchase, 2008; Vodafone, 2009, p.2). However, following the EU (2007, p.3), Ofcom (2009a, pp.4 & 18) has adopted a rather wider concept of “media literacy”, as “the ability to use, understand and create media and communications” where

- “use” means being able to send a text or email;
- “understanding” relates to undertaking consumer tasks and
- “creating” involves blogging.

Morris (2009, p.9) defined “’Digital Life Skills” as “a set of basic ICT skills an individual requires to use a computer to safely enter, access, and communicate information online”. Howsoever defined, in early twenty-first century Britain, as increasing reliance is placed on communicating using digital technologies, those who cannot use digital communication technology are, in effect, ‘digitally illiterate’.

To what extent basic literacy is associated with digital illiteracy is not clear, but given the reliance on reading and writing to use the internet effectively, there is likely to be some association. In 2002-03 one in six adults under retirement age had basic literacy below the standard expected of an 11 year old, and there was little variation by age (DfES, 2003 pp.1 & 3; Literacy Trust, 2007). Castells et al (2007, p.253) argued that “no special technical skills” are needed to use a mobile phone. That is an oversimplification. Even for making a voice call, mobiles are more difficult to use than fixed line phones, especially for those who do not have good eyesight and dexterous fingers (Castells et al, 2007, pp.256-7). To use the more advanced features, some digital literacy is required for mobiles, albeit minimal. However, digital literacy is more usually used to mean computer literacy.

There is a significant minority who do not use the internet. In 2003, 15 percent of adults under retirement age had never used a computer and only 1 in 10 had good practical computer skills, as measured by the ability to undertake “22 practical *Windows*-based tasks” (DfES, 2003, p.7). It was noted above that in 2007, only 60 percent of households had internet access. That means 40 percent of households did not. In spring 2008, the internet played no part in the lives of a quarter of adults in UK: 70 percent of those aged 65 and over (ONS, 2008). According to the *Digital Britain* report (BIS, 2009, p.32), 15 million adults did not use the internet. Even by early 2009, 30 percent of those aged 14 and over did not use the internet (Dutton et al, 2009, p.4). Non-use of the internet seems to be due to various combinations of lack of skill, lack of resources and, most importantly, lack of interest (ONS, 2008d; Dutton et al, 2009, p.4). Those who are aged 65 and over, who left education at secondary school level, who are in social class DE and who are financially poor are least likely to be able to access or use the internet effectively (Ofcom, 2009a, p.13). Most non-users have never used the internet and do not expect to do so in the future (Dutton & Helsper, 2007, pp.4 & 9). But there is an important minority who have used the internet in the past but no longer do so (Katz & Rice, 2002, pp.67-81). In Britain, this accounts for around 6 percent of households (Dutton et al, 2009, p.7). However, for simplicity, the model assumes that once an agent adopts the internet, it continues to do so.

In 2008, those with no formal qualifications were almost half as likely to have access to the internet at home as those with degrees (Table 8.2.1).

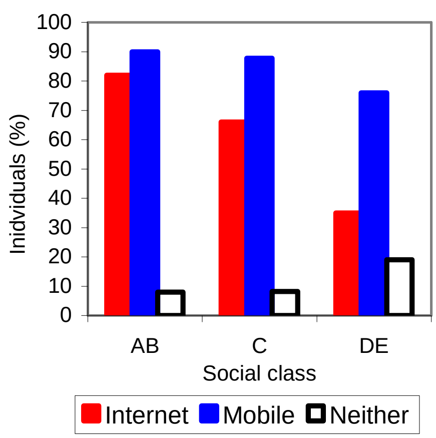
Table 8.2.1: Adults under 70 with household internet access by educational qualifications: UK: 2008.

Percent

Education	
Degree	93
Higher	86
A-Level	89
GCE/GCSE (A-C)	82
GCE (D-G)	74
No formal qualification	56

Source: ONS (2008d).

Fig. 8.2.3: Internet and mobiles by class: 2007.



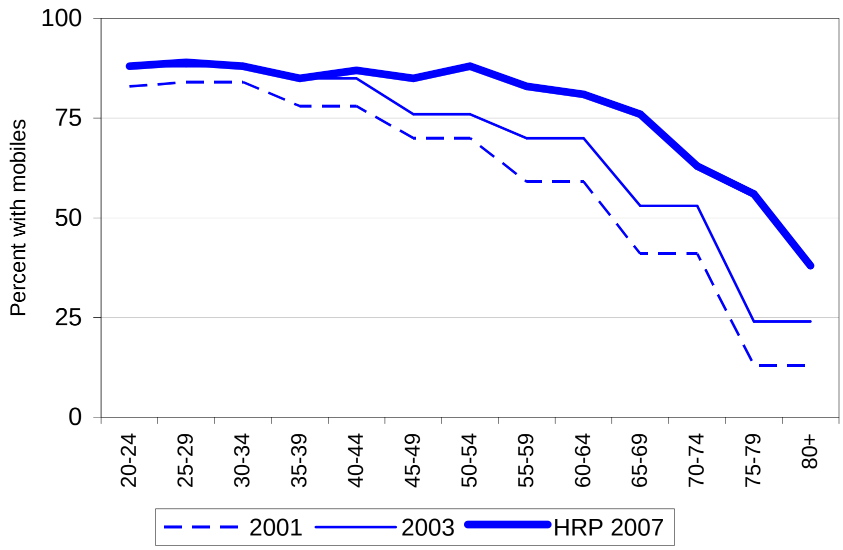
Source: Ofcom (2008a, Table 3)

Those in class DE are less than half as likely as ABs to be online (Fig. 8.2.3). Dutton et al (2009, pp.16-17) found that these differences persisted in 2009. Use of mobiles declines with class too, but much less so.

As long ago as 1994, Haddon & Silverstone pointed out that for “many of the elderly in particular, the social trend of automated offices from the 1980s had arrived too late in their working lives; for many of this generational cohort, computer technologies remained beyond their horizons”. On that basis many of those who retired before around 1990 were unlikely to have used PCs at work. Taking the standard retirement ages, this implies that those who are now in their 80s will be much less likely to be digitally literate. Thus Lai (2008) distinguished between the ‘young-old’, aged 60 to 75, who had used digital communication technologies at work or to manage family life and the ‘old-old’ (75 and over) who were not familiar with them at all.

Adoption of mobiles declines with age. In 2001 nearly 9 out of 10 of adults under 25 had a mobile phone compared to under a quarter of those aged 75 and over. By 2007, the proportion of “household reference persons”, generally aged between 25 and 85 (see Chapter 7), with mobiles still fell with age, although less sharply than previously (Fig. 8.2.4).

Fig. 8.2.4: Mobiles by age: 2001, 2003 & 2007.



Sources:
2001 & 2003: ONS, 2004; Table 13.14;
2007: Special tabulation from *Family Spending Survey*;
2007. HRP = “household reference person”.

Use of the internet falls with age too. And even by 2008, this was particularly marked for those aged 65 and over, only 30 percent of whom had ever used the internet (as shown in the top panel of Fig. 8.2.5). Unfortunately this data from the ONS *Internet Access Survey* does not distinguish between the younger elderly and the very old. To try to fill this gap, a special tabulation was commissioned from ONS showing households online by age of the 'household reference person' (the replacement for 'head of household'). Although this series does not represent the under 25s well, it does provide detailed figures for those aged 65 and over. Subsequently further data was found from Ofcom which distinguished those aged 75 and over. While these three series measure internet use in slightly different ways, they are all for 2007. The bottom panel of Fig. 8.2.5 and Table 8.2.2 illustrate how important it is to distinguish between the 'young elderly', aged 65 to 69, almost half of whom used the internet in 2007, and the 'old elderly', aged 80 and over, of whom only 15 percent used it.

Table 8.2.2: Internet use by those aged 65 and over: 2007.

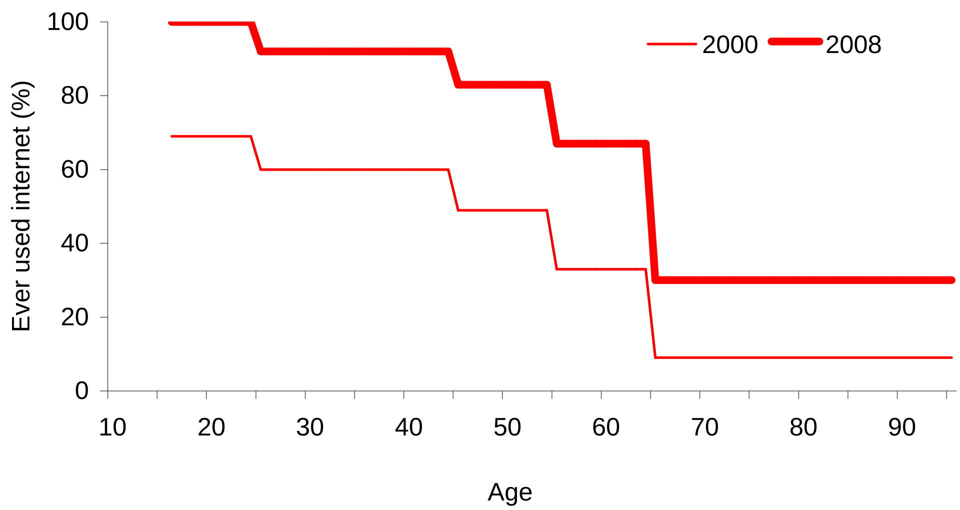
<table>
<tr><th>Age</th><th>Percent ever used the internet
(ONS)</th><th>Percent with internet at home
(Ofcom)</th><th>Percent who use internet
(Dutton)</th><th>Percent of HRPs with internet connection (ONS)</th></tr>
<tr><td>65-69</td><td rowspan="4">29</td><td rowspan="2">35</td><td rowspan="2">40</td><td>46</td></tr>
<tr><td>70-74</td><td>35</td></tr>
<tr><td>75-79</td><td rowspan="2">9</td><td rowspan="2">20</td><td>24</td></tr>
<tr><td>80+</td><td>15</td></tr>
</table>

Sources: ONS (2008a, 2008d) OIS: Dutton et al, 2009, p.17; HRP: Special tabulation from *Family Spending Survey* 2007.

Thus age and class are key determinants of adoption. As well as replicating the overall adoption rates, the model also aims to replicate these age and class variations by allocating each agent a digital literacy score. The details are in Box 8.2.3, with the resulting distributions shown in Fig. 8.2.6.

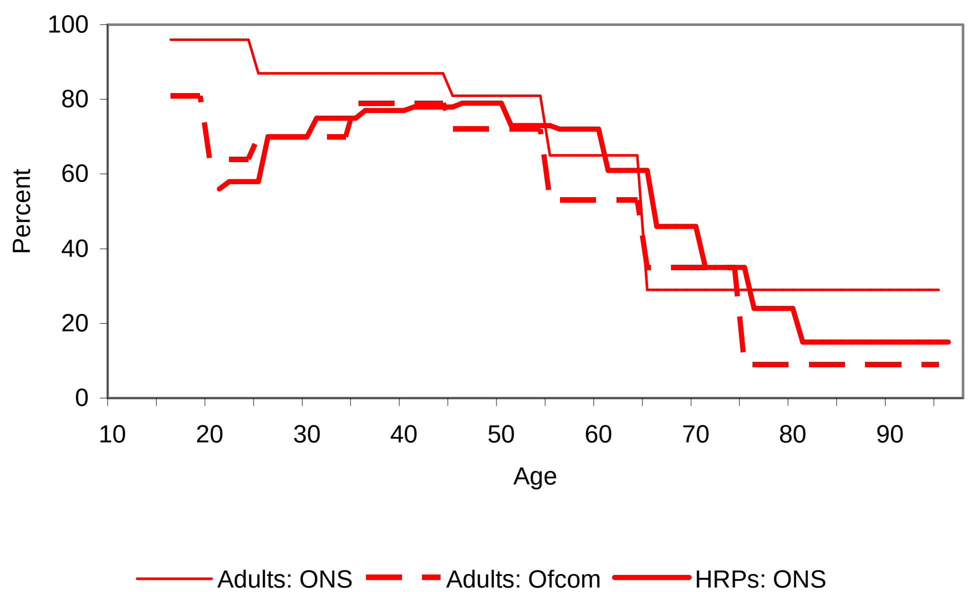
Fig. 8.2.5: Internet use by age: 2000-2008.

(a) The proportion of adults who have ever used the internet: GB, 2000, and UK, 2008.



Source: ONS (2008d); ONS (2009f).

(b) Internet use by age: alternative measures in 2007



Sources: ONS (2008a, 2008d)
HRP = "household reference person": Special tabulation from *Family Spending Survey* 2007.

Box 8.2.3: Calculation of digital literacy scores.

Logistic curve.
Percent adopting =

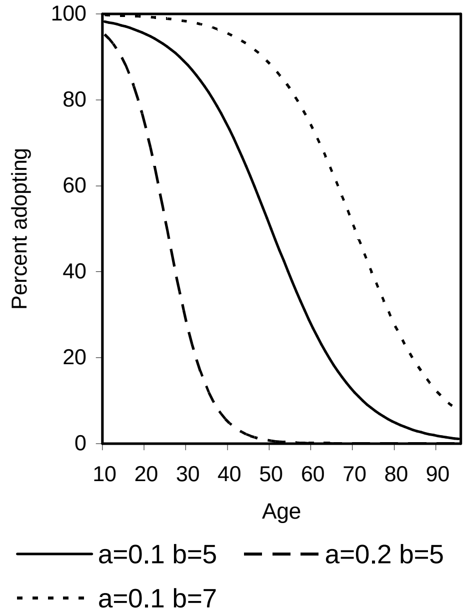
$$1-\frac{1}{1+e^{(-aAge+b)}}.$$

The higher is *a*, the greater the effect of age. The higher is *b*, the further right the curve lies.

Setting *a* = 0.1 and *b* = 5 implies that increasing age has little effect on adoption up to 30 and after 70, as shown in the middle, solid line, in the graph in the right hand panel.

Keeping *b* = 5 but setting *a = 0.2* would mean age has a much faster effect with no one over age 50 adopting, as shown in the dashed line.

Keeping *a* = 0.1 but setting *b* = 7 would imply that half those aged 70 and over adopted, as shown in the dotted line.



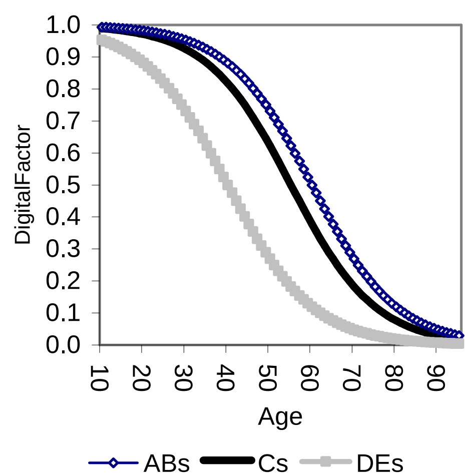
So the digital factor is defined as:

$$1-\frac{1}{1+e^{(-aAge+b)}}$$

where *a* = 0.1 and *b* varies by class:

- for ABs, *b* = 6,
- for Cs, *b* = 5.5 and
- for DEs, *b* = 4.

This digital factor is the same for all agents of the same age and class and ranges between 0 and 1: for example, 10 year old ABs have a score of 0.99 while 95 year old DEs have a score of 0.004. The results are illustrated on the right.

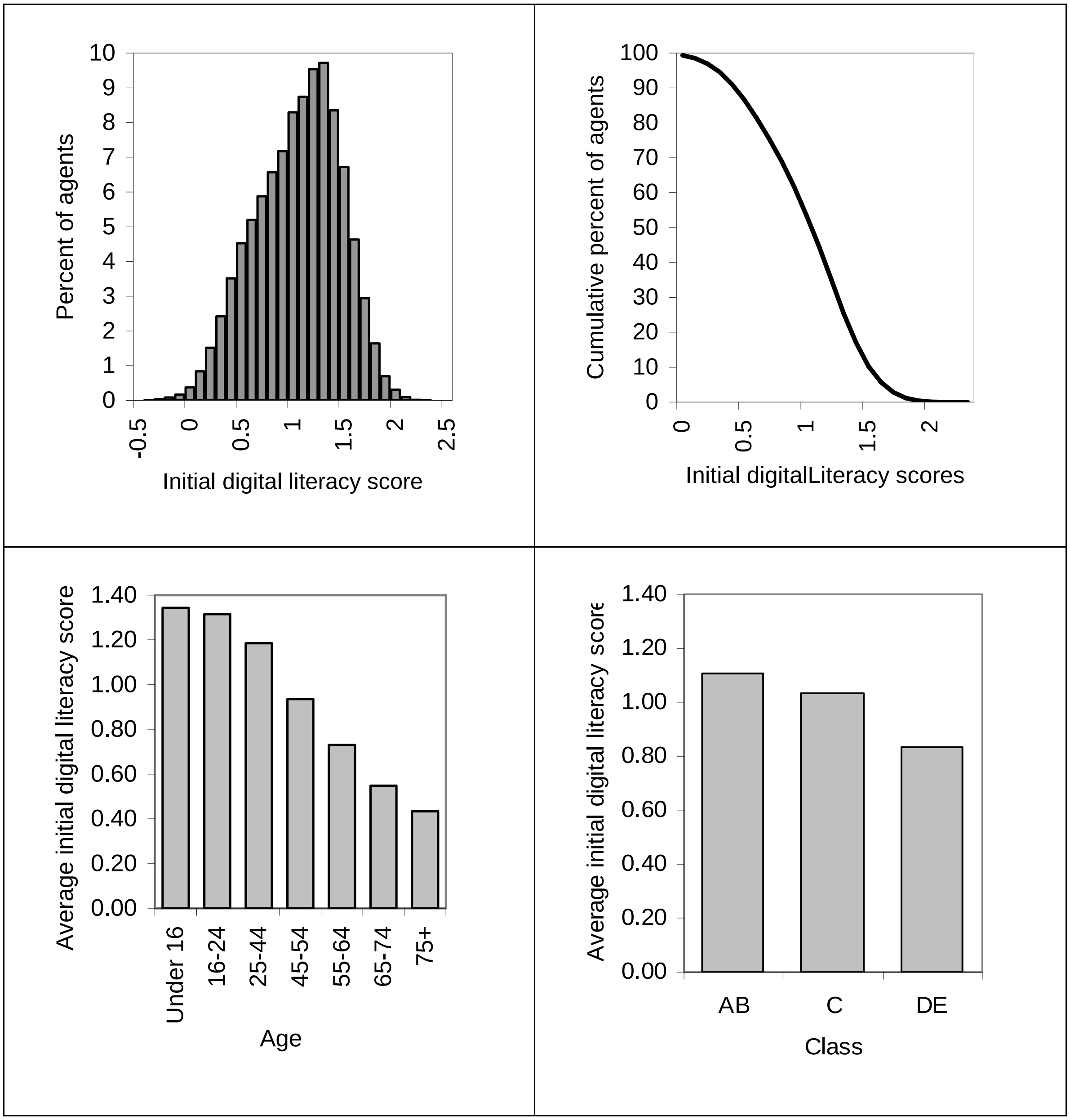


To introduce variation between agents of the same age and class, the digital factor is then taken as the mean of a random normal distribution, with a standard deviation of 0.25. The number generated becomes the agent's digital literacy score.

The scores are normalised with a mean of 1.

The results are shown in Fig. 8.2.6.

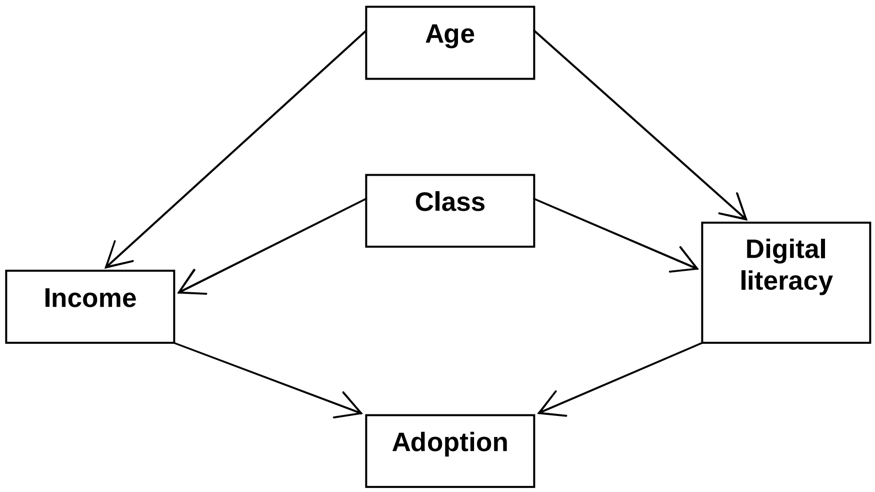
Fig. 8.2.6: Model results: distribution of initial digital literacy scores.



Income and literacy

Thus in the model, age and class determine adoption though income and digital literacy as shown in Fig. 8.2.7

Fig. 8.2.7: Role of age and class in the model.



If there were no income or digital literacy thresholds, all agents would be online. The higher the income and digital literacy thresholds are set, the fewer will be online. The income and digital literacy thresholds were chosen to generate as closely as possible the 1998 adoption figures: about a quarter with mobiles and 10 percent online.

- The income threshold was set at 1.33 for mobiles and 0.9 for computers (where the initial average income equals 1), although this was in effect blurred to allow for the fact that some poorer people do choose to buy digital communications or, in the case of internet connections, bought computers at an earlier time when their income was higher: 5 percent of those below the threshold for PCs and 10 percent of those below the mobile income threshold were allowed to adopt.
- The mobile digital literacy threshold was set at 0.5 and the internet digital literacy threshold at 1.4 (where the initial average is 1). If there were no income thresholds initially, some 85 percent would have had mobile phones and about one in six would have been online.

Incomes rise at 2.4 percent a year. The digital literacy score is raised in two ways. For the population as a whole, the average score rises through the ‘generation effect’; older, less digitally literate agents are replaced by younger, more digitally literate agents. For the individual, it rises due to social pressures, as explained next.

Personal and social networks

As noted in *Digital Britain* (BIS, 2009, p.32), social pressures can provide an important incentive to acquire digital skills. To reflect this, the model assumes that an agent’s digital literacy score rises in line with both the proportion of adopters in its personal network, to reflect the direct influence of friends and family, and the overall proportion in society, to reflect general economic and social pressures. The two are given different weights. The personal network is determined by the social reach. The social network, means all the agents in the model. Thus adoption is driven by a positive feedback loop: as more agents adopt, more will adopt.

For mobiles, there is no personal network effect because mobiles can be used for voice calls to fixed line phones and, as shown in Table 8.1.3, almost everyone has one or other types of phone. By 2001, Oftel (2001c, para 4.3) reported that “the mobile has created a culture in which it is assumed that most people are contactable all the time as a matter of course”. This social pressure is reflected in the assumption that the social network weight is 0.1. This means that the scope for mobile digital literacy scores to increase is limited: those with scores of 0.4 or less will never reach the adoption threshold of 0.5.

For the internet, a personal network effect is assumed in addition to the social network effect: the personal network effect is given a weight of 0.75. There is therefore much greater scope for social influence to increase digital literacy scores. Nevertheless, no one with a digital score of less than 0.55 will ever go online. (Details in Box 8.2.3.)

Box. 8.2.4: Combinations of personal and social networks needed to reach digital literacy thresholds.

The digital literacy score is given by the base score, which is determined by age and class, as described in Box 8.2.3:

+ personal network weight x % personal network adopting
+ social network weight x % whole social network adopting

Mobiles

Personal network weight = 0
Social network weight = 0.1
So the digital literacy score = base score + 0.1 x % all agents with mobiles.
If the base score = 0.4 and adoption is 99%, their score is only raised to
0.4 + 0.1 x 0.99 = 0.499
As the threshold is 0.5, such an agent will never adopt.

Internet

By definition, if the agent's score is 1.4, the agent will adopt with no social influence.

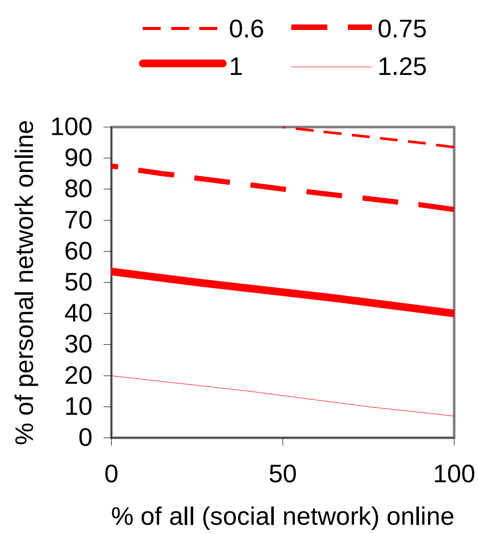
If an agent initially has a digital literacy score of 1 – the average – its score will reach the internet threshold of 1.4 when just over half of its personal network are online even if almost no other agents are online (as indicated by the solid line).

If, however, its initial score is 0.6, then it will only reach the online threshold when over 90 percent of its personal network is online (as indicated by the broken line at the top right hand corner).

Those with scores below 0.55 will never go online.

Personal network weight = 0.75
Social weight = 0.1

Initial digital literacy scores



The social reach for personal networks is set to 15, giving an average personal network of 7 (as shown in Fig. 4.1.2). As in Chapter 7, the agents are grouped by class (see Box 7.4.1). As in previous models, 'socialshifting' is assumed whereby a proportion of agents move randomly each time period to reflect social movement. In this model, it is assumed that 5 percent of agents shift each period. The model and key assumptions are summarised in Box 8.2.4.

Box 8.2.5: Summary of adoption model and base case assumptions to 2007.

Initialisation
Agents created and distributed randomly.
Agents in top left quadrant designated class AB, in bottom right hand quadrant, class DE. Others, class C as described in Box. 7.4.1.
Agents allocated ages as described in Box 8.2.1.
Agents allocated income as described in Box 8.2.2.
Digital literacy calculated based on age and social class as described in Box 8.2.3.
Mobiles, PCs and internet access allocated to agents whose digital literacy and household incomes exceed the appropriate thresholds (but some of those who are sufficiently digitally literate but whose income is too low are allocated mobiles and PCs.)
Initial summary statistics recorded.

Execution
Agents age and die. Replacement agents are created.
Agents move by socialshifting.
Incomes grow and prices fall.
Agents reaching 65 retire.
Agents' digital literacy score re-calculated, taking into account the personal and social network effects.
Mobiles, PCs and internet access allocated to agents whose digital literacy and household incomes exceed the appropriate thresholds.
Summary statistics recorded.

Base case assumptions to 2007
Both mobile and internet
Incomes grow at 2.4% a year
Socialshifting rate: 5%
Digital Literacy parameters: *a*: 0.1 and *b* varies by class:
- for ABs, *b* = 6,
- for Cs, *b* = 5.5 and
- for DEs, *b* = 4.

Standard deviation = 0.25
Social reach = 15

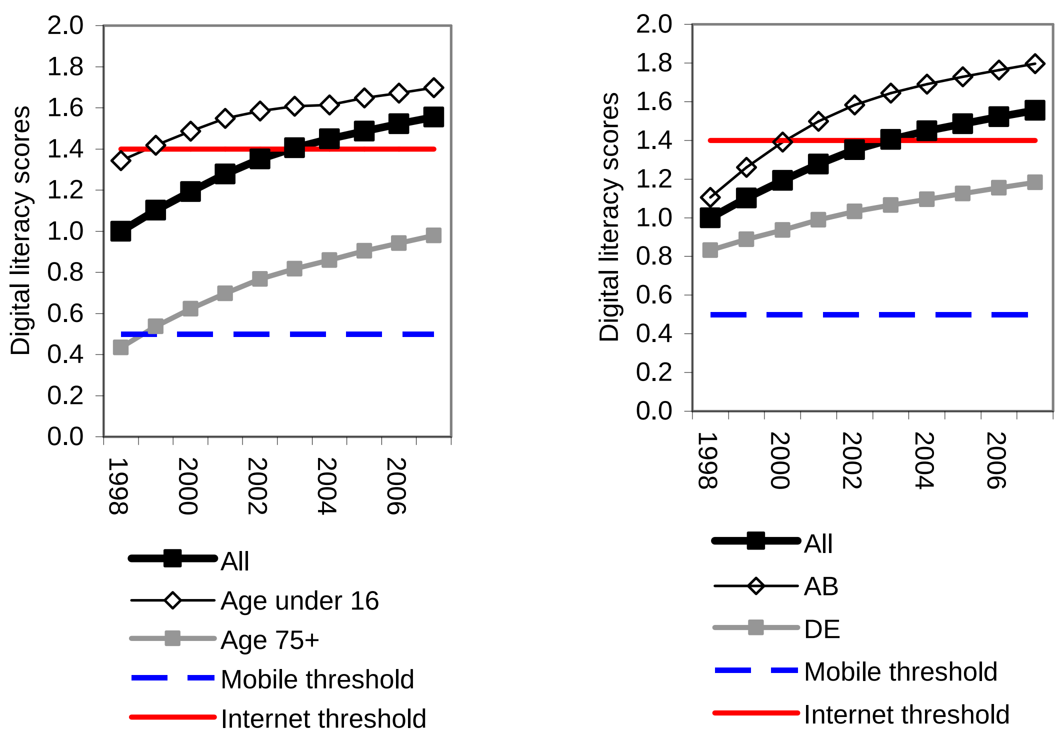
	Mobile	**Internet**
Coverage	1998: from age 18. Thereafter from age 10.	From age 10
Network effects		
- Personal network weight	0	0.75
- Social network weight	0.1	0.1
Digital literacy thresholds	Mobile adoption: 0.5	PC adoption: 1 Internet adoption: 1.4
Initial income thresholds	1.33	0.9
% 'poor' households adopting	10%	5%
Price fall per year	5% a year	20% a year

Results

As noted above, the digital literacy scores rise due to the 'generation effect' and the positive feedback loop resulting from the influence of the personal and social networks on the digital literacy scores. Fig. 8.2.8 shows how the scores rose overall and for different ages and classes:

- in 1998, the average score for all classes and all ages except the oldest exceeded the mobile digital literacy threshold of 0.5;
- the overall average digital literacy score exceeded the internet threshold of 1.4 by 2003 but those aged 75 and over and those in class DE were on average still below the threshold in 2007.

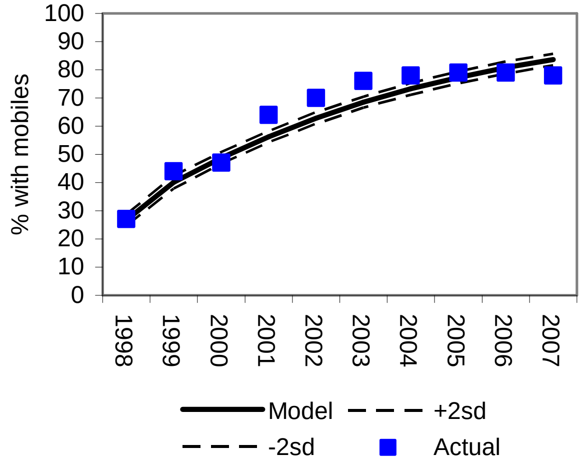
Fig. 8.2.8: Model results: increase in average digital literacy scores by age and class: 1998-2007.



The model broadly tracks both the overall growth of households with mobiles and the growth in the top and bottom income deciles between 1998 and 2007, as well as replicating mobile adoption by class and age in 2007 (as shown in Fig. 8.2.9).

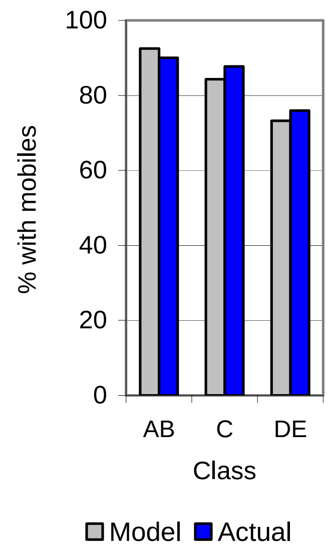
Fig. 8.2.9: Model results: mobiles.

a) Adoption from 1998 to 2007.



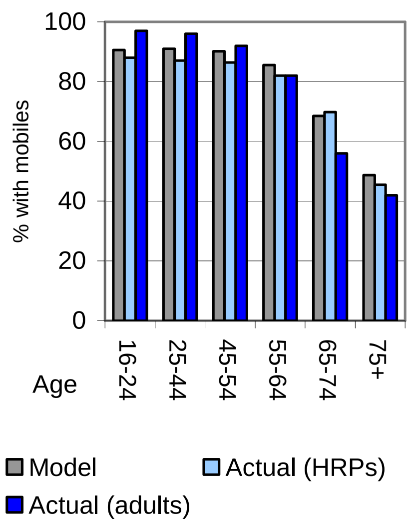
Source: Actual: ONS (2008a).

b) Adoption by class in 2007.



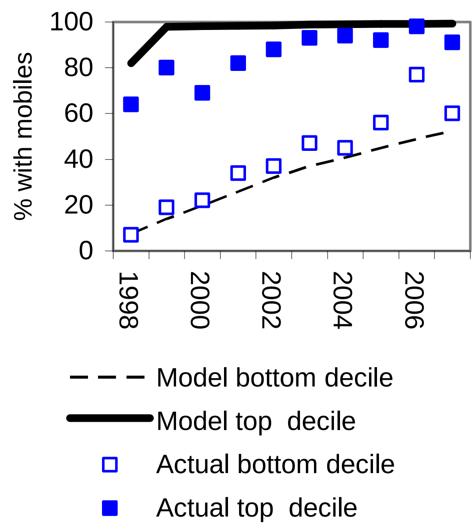
Source: Actual: Ofcom (2008a).

c) Adoption by age in 2007.



Sources: Actual HRP: ONS (2009) special tabulation. Actual: Ofcom (2008a).

d) Adoption by top and bottom income deciles, 1998-2007.

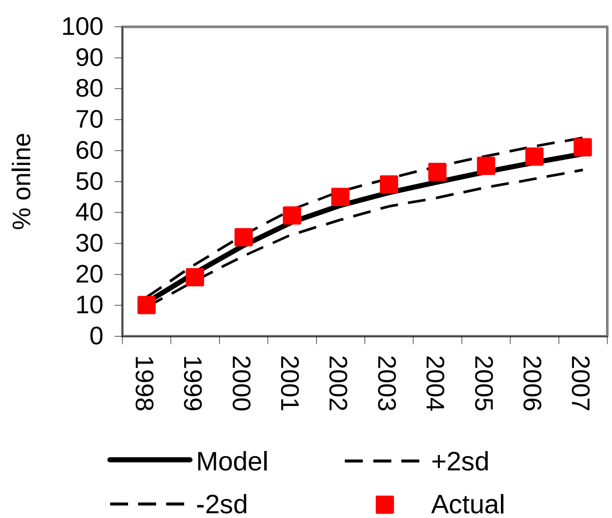


Sources: Actual: ONS (1998,1999,2002,2003a, 2003b, 2005b, 2007d, 2008a).

Fig. 8.2.10 shows the results for the internet. The model tracks the growth of households online between 1998 and 2007 well and broadly replicates the proportions in the top and bottom income deciles between 1998 and 2007. It also reproduces the proportion of different classes on the internet in 2007. However, the model rather over-predicts adoption among those under 25 and under-predicts adoption of those 45 and over. This is discussed further below.

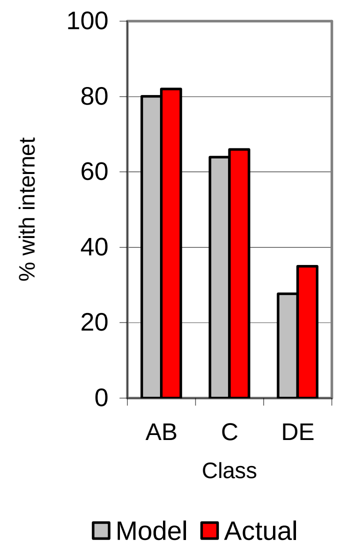
Fig. 8.2.10: Model results: internet.

a) Adoption from 1998 to 2007.



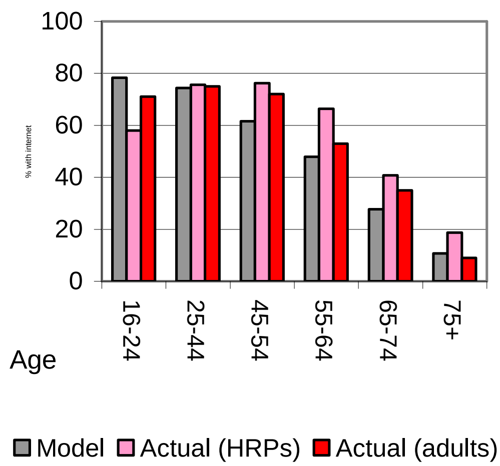
Source: Actual: ONS (2008a).

b) Adoption by class in 2007.



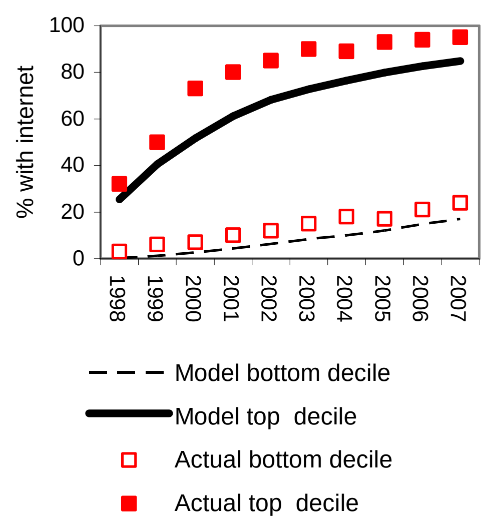
Source: Ofcom (2008a).

c) Adoption by age in 2007.



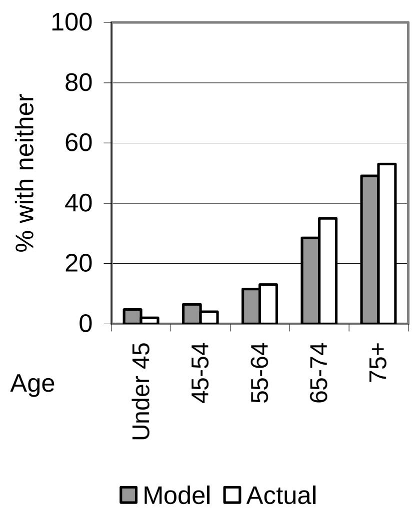
Sources: Actual (HRPs): ONS (2009) special tabulation. Actual (adults): Ofcom (2008a).

d) Adoption by top and bottom income deciles, 1998-2007.



Source: Actual: as Fig. 8.2.9.

Fig. 8.2.11: Model results: percent with neither mobiles nor internet by age in 2007.



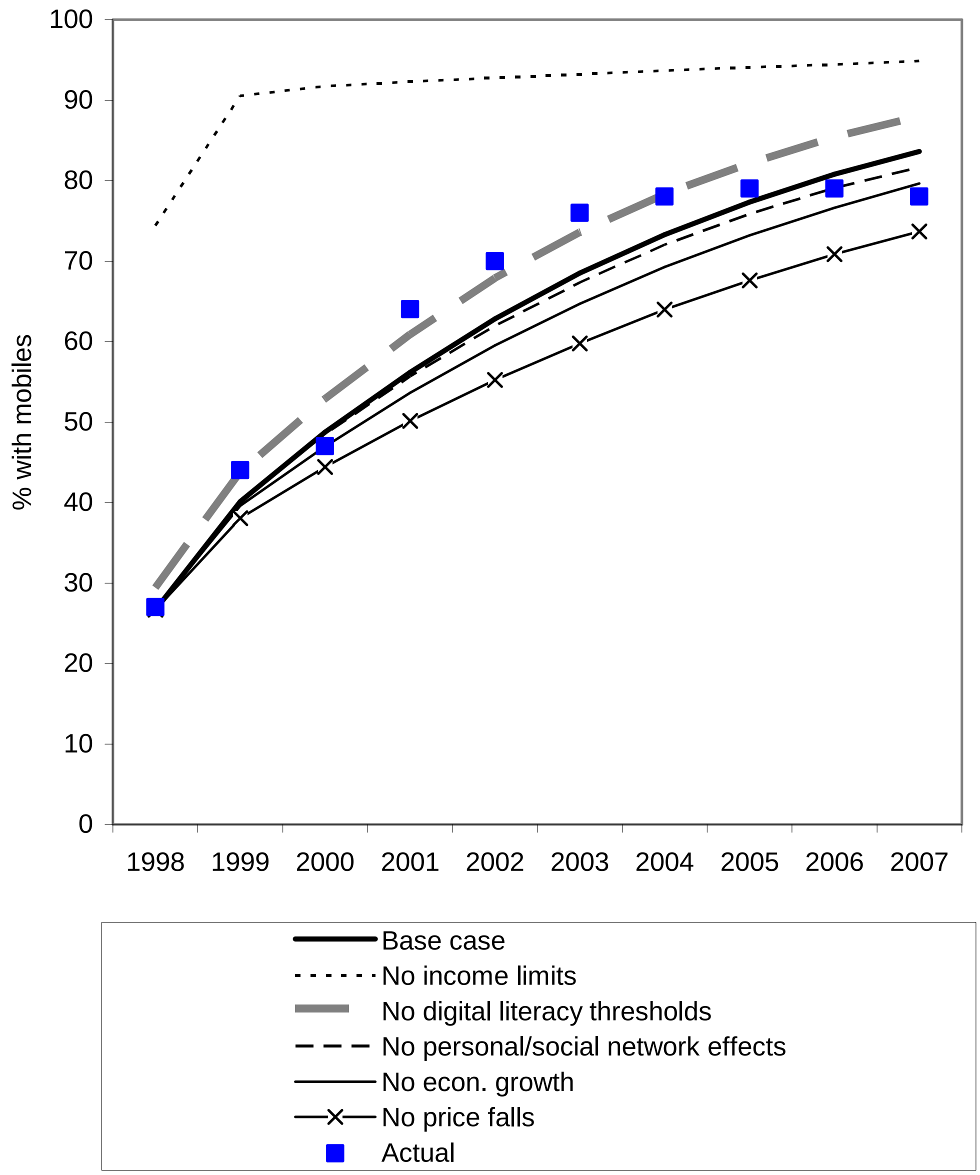
Source: Actual: Ofcom (2008a)

According to Ofcom (2008a), 58 percent of adults had both mobiles and the internet in 2007: the model shows 55 percent having both while 12 percent had neither rising to half of those aged 75 and over. Fig. 8.2.11 shows how the model replicates the observed variation by age of those with neither mobiles nor internet access in 2007.

The sensitivity of the model to key assumptions was tested. The results for mobile adoption are shown in Fig. 8.2.12. Removing the social network effect or mobile digital literacy thresholds had little effect on the rate of adoption according to the model. It is the economic factors which appear to be most significant. The model suggests that:

- with no price reductions or no economic growth, the adoption of mobiles would have been lower between 2001 and 2006;
- without the income thresholds, adoption would have been much faster.

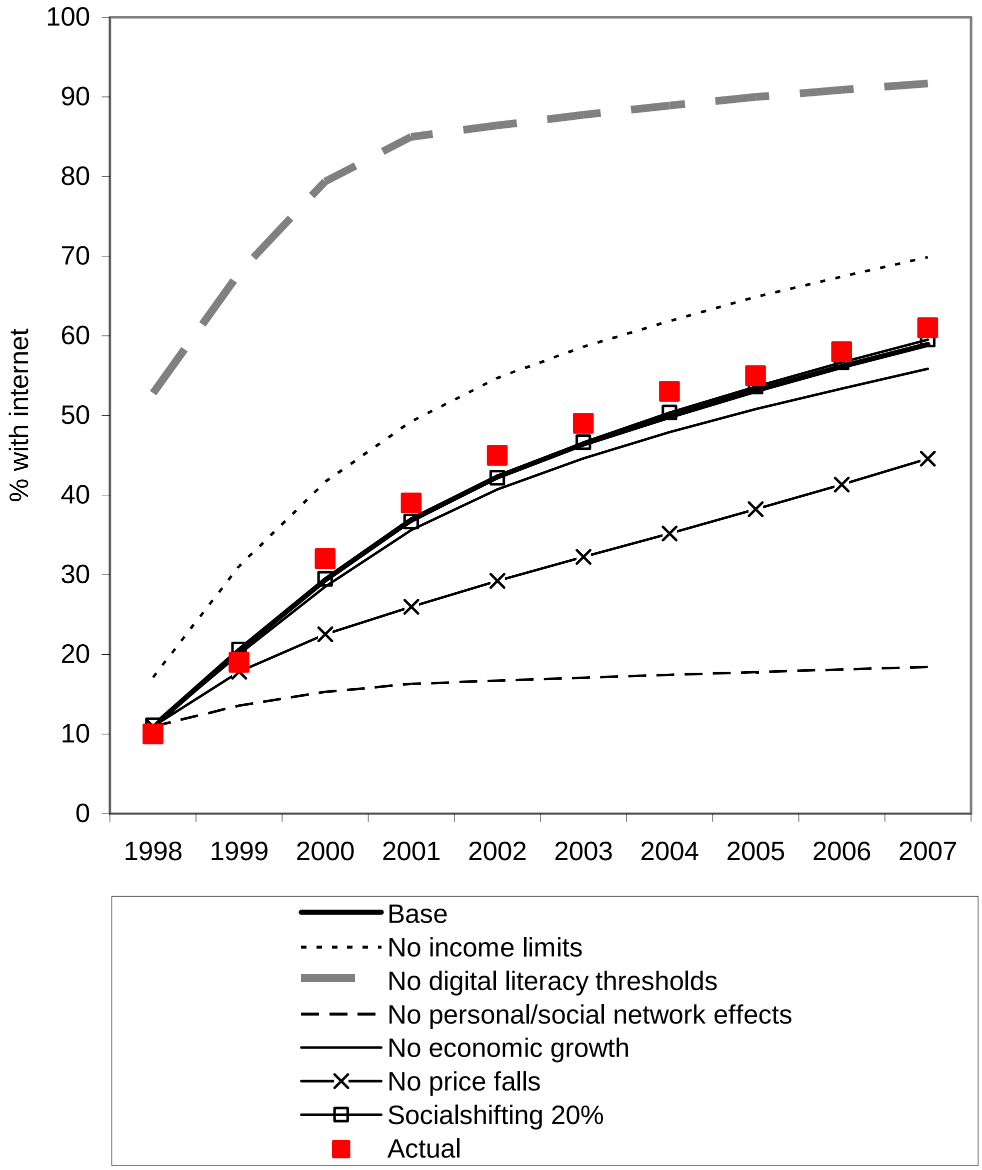
Fig. 8.2.12: Model results: mobile adoption: sensitivity to key assumptions.



Source: Actual: ONS (2008a).

The sensitivity results for internet adoption are shown in Fig 8.2.13. In contrast to the results for mobiles, the personal and social network effects and the digital literacy thresholds were important. With no income limits adoption would have been slightly faster, and with no price falls, slightly slower. Economic growth seems to have had little effect. Nor did increasing socialshifting to 20 percent each year.

Fig. 8.2.13: Model results: internet adoption: sensitivity to key assumptions.

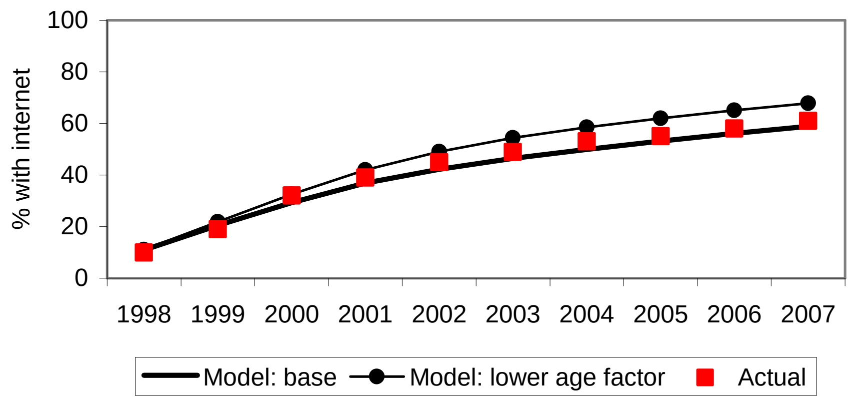


Source: Actual: ONS (2008a).

As digital literacy turns out to be so important, the effect of changing the distribution of digital literacy scores was investigated. This was done in two ways. As noted above, the parameters used tended to overestimate the effect of age. Thus the age factor in the calculation of the digital literacy score was reduced from 0.1 to 0.08. In order to reproduce the percentage online in 1998, the internet threshold was also reduced, to 1.33. On this basis the model did generate a better distribution by age for 2007 but the overall adoption level was higher than actually occurred. (See Fig. 8.2.14.)

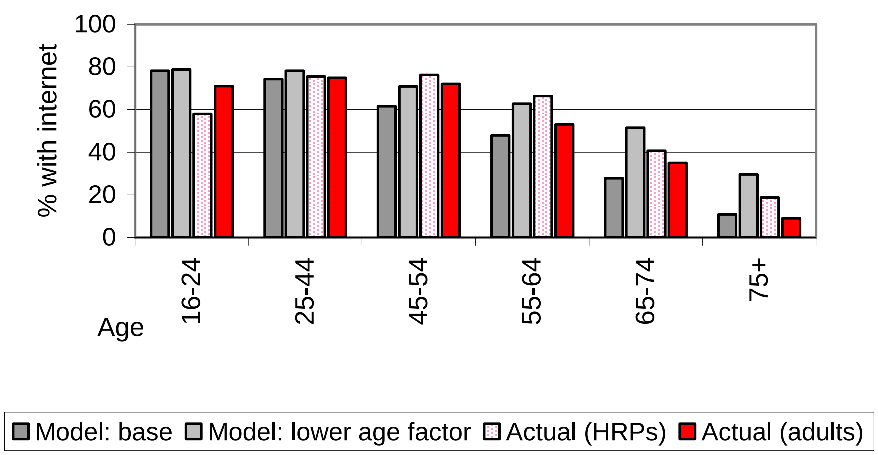
Fig. 8.2.14: Model results: internet adoption: assuming age factor of 0.08 and internet threshold of 1.33.

a) From 1998 to 2007



Source: Actual: ONS (2008a)

b) By age in 2007



Sources: Actual (HRPs): ONS (2009, special tabulation). Actual (adults): Ofcom (2008a).

Second, a more radical approach was taken. It was assumed that there were no age or class effects but that digital literacy scores were otherwise calculated as before. On that basis, only 5 percent of agents would have exceeded the internet threshold of 1.4 initially compared to 17 percent in the base case. As a result only 3 percent would have been online instead of 10 percent. The method and results are explained in Fig. 8.2.15.

Fig. 8.2.15: Model results: distribution of initial digital literacy scores: base case compared to no age and class effects.

Method

As explained in Box 8.2.3, the calculation of the digital literacy scores was based on the digital factor, which was defined as:

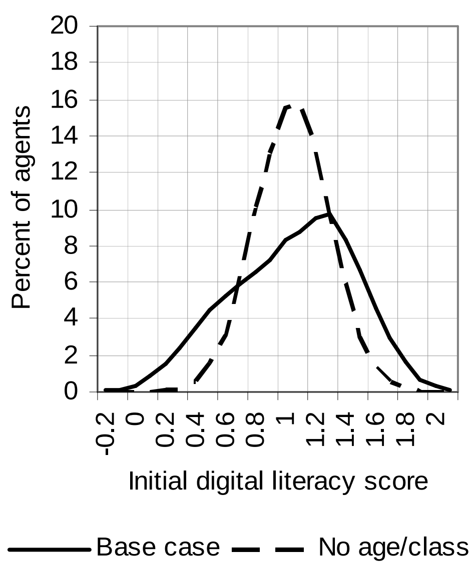
$$1-\frac{1}{1+e^{(-aAge+b)}}$$

where *a* = 0.1and *b* varied between 4 and 6 depending on class. In this alternative scenario, both *a* and *b* are set to 0. Thus the digital factor was reduced to

$$1-\frac{1}{1+e^{0}}$$

which equals 0.5 for all agents. As before, the digital factor was taken as the mean of a random normal distribution with a standard deviation of 0.25 and normalised to give a mean of 1.

Results



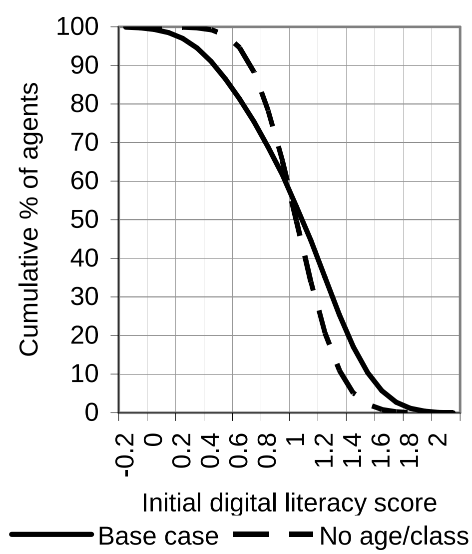
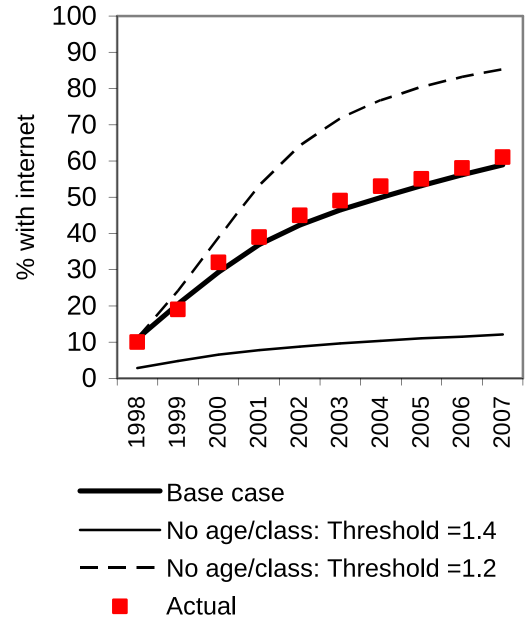


Fig. 8.2.16: Model results: internet adoption assuming no age or class effects on digital literacy.



Source: Actual: ONS (2008a).

With no age or class effects on digital literacy scores and the threshold set at 1.4, adoption reaches only 12 percent by 2007, as shown by the thin line in Fig. 8.2.16 (instead of 60 per cent). However, the digital literacy threshold was chosen on the basis that about 10 percent would be online initially and to achieve this with no age or class effects, the threshold would have to be set at 1.2. But this lower threshold results in much faster adoption (as shown by the dashed line in Fig.8.2.16). Furthermore, using this method of calculating digital literacy scores fails to reproduce the observed pattern of class and age take-up.

This is an interesting result. Not only does it imply that the assumptions made about digital literacy are plausible, but also suggests that class and age were important in generating a set of early adopters who in turn encouraged adoption through the network effect. With no age and class effect on digital literacy, the initial take-up of the internet in is low and thus, due to the weakness of the network effect adoption of the internet does not ‘take-off’. In effect, no critical mass is reached.

8.3 Model of Use

This Section extends the adoption model to examine use of mobiles and the internet.

Mobiles

Mobiles can be used to make voice calls and send texts and, more recently, picture messages, both still and moving. Castells et al (2007, p251) argued that the key characteristic of mobile devices is not their ability to link people on the move but the fact that they are person-to-person devices in contrast to fixed line phones which provide place-to-place connectivity. They asserted that this connectivity has strengthened individualism. By providing direct person-to-person connectivity, mobile phones do appear to have increased connectivity: the total number of voice calls has risen and texting continues to grow. And new practices have been observed, for instance the 'goodnight' text messages sent between teenagers (Taylor & Harper, 2003; Harper & Hamill, 2005; Castells et al, 2007, pp.179-184). Thus Ling has argued (2008, pp.186-7) that the changes we are observing are not a simple shift from gemeinschaft to gesellschaft but rather that social cohesion is being "recalibrated".

Mobile phones have encouraged travel in at least three ways: by freeing people from fixed line phones, by allowing better use of otherwise 'dead' time while travelling and by facilitating travel arrangements.

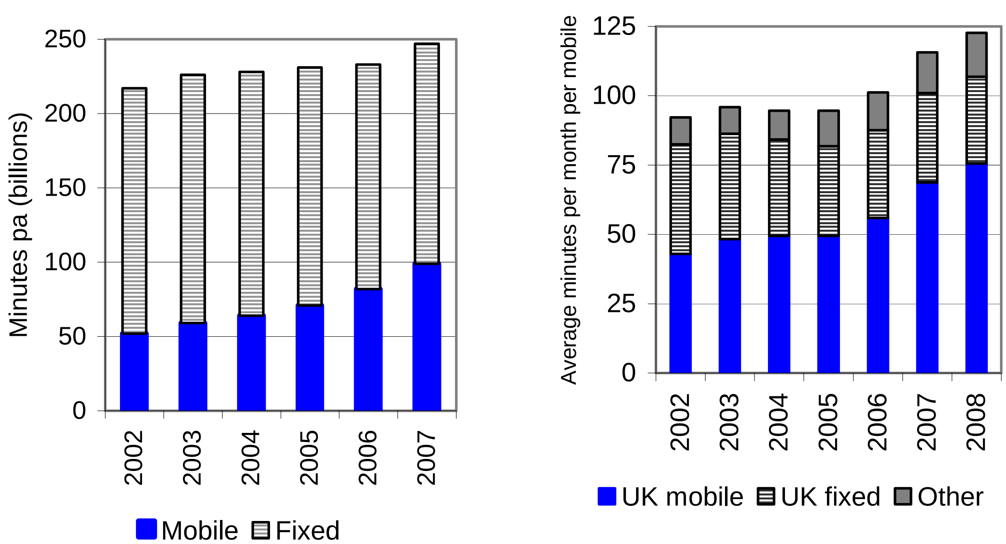
- Because mobiles provide person-to-person rather than place-to-place communication, people are freer to move: they are not tied to a place while awaiting a call.
- Because mobiles enable people to communicate with others while on the move, they can make use of otherwise 'dead time' (Castells et al, 2007, p.176).
- Because mobiles facilitating flexibility and spontaneity, they have enabled meetings that would not otherwise have taken place. Castells et al (2007, p.249) noted the rise of "ad hoc groupings to take precedence over formal structures of interaction and participation". The arranging of meetings 'on the fly' has been

noted by many (for example, Ling & Yttri (2002), Ling et al (2005), Matsuda (2005, pp.128-129) and Schiano et al (2002)).

Mokhtarian & Salomon (2002, pp.163-4) reported two studies of the impact of mobile phone use on travel in the US. A study undertaken in 1991 found more respondents reported fewer, shorter trips than more, longer trips implying substitution dominated (Yim, 1994). A later study indicated that use of mobiles generated trips rather than substituting for them (Yim, 2000).

In 2008, Ofcom (2008b, pp.294-6) reported that 70 percent of people with mobiles and fixed line phones used mobiles when they were at home and that a major reason for this was the price, especially the desire to use up inclusive minutes on mobile contracts. Not surprisingly therefore, the volume of voice calls from fixed lines has fallen since 2003, while that from mobiles has risen, driven by increasing mobile-to-mobile use (Fig. 8.3.1). However, total calling has increased; thus the UK is no exception to Castells et al's (2007, p.7) observation that: "In most countries mobile phones have not yet become substitutes for wired phones but rather act as a complement".

Fig. 8.3.1: Outbound call volumes: 2002-2007/8.

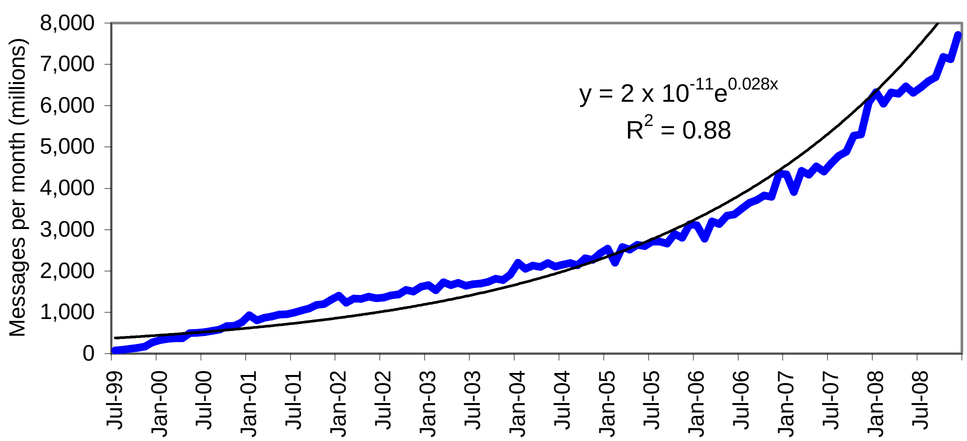


Source: Ofcom (2008b, pp.294 & 339); Ofcom (2009b, p.253).

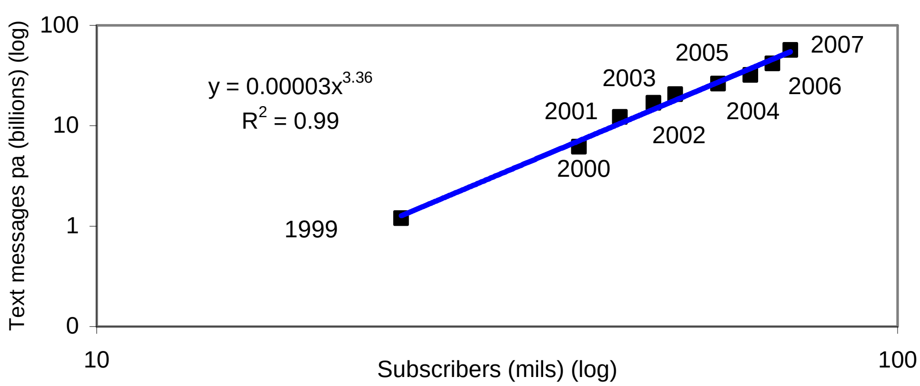
Although voice calls can be made between mobile and fixed phones, text and picture messaging are almost invariably sent between mobiles. Since 1999, the number of text messages sent in the UK has grown at almost 3 percent a month, or by over a third each year (top panel of Fig. 8.3.2). This growth is faster than can be explained simply by the increase in the number of mobiles. As noted in Chapter 3, the number of possible links in a network increases by the square of the number of nodes. Taking nodes to be mobiles and links as text messages, the lower panel of Fig. 8.3.2 shows that the number of texts grew by a power of three, rather than two as implied by just the growth in nodes. In other words, the growth in texting cannot be explained solely in terms of the growth in adoption of mobiles.

Fig. 8.3.2: Growth of text messaging (SMS): UK: 1999-2008.

a) Monthly data



b) By number of subscribers



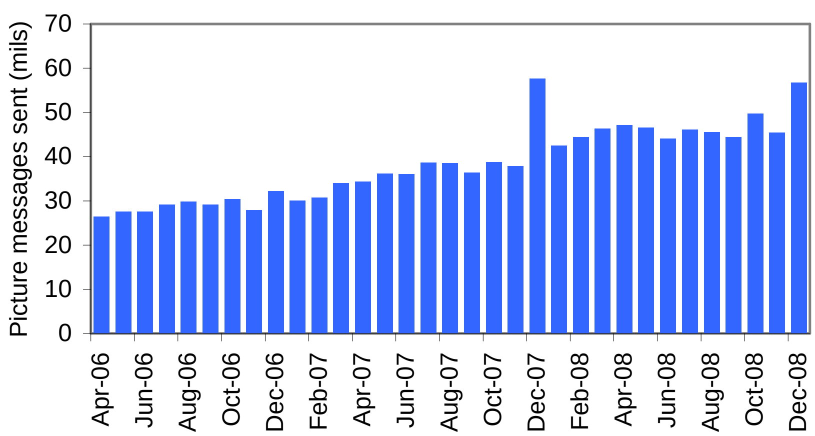
Sources: Ofcom (2008b, p.309); MDA (2007 & 2007-2009)

Multimedia messaging (MMS) arrived in the UK in around 2002-3 with the introduction of so-called 2.5G phones and has become increasingly available (Ofcom, 2008b, p.305). Despite this, the use of SMS continues to rise: according to Ofcom (ibid) the reasons are “complex”, including culture and pricing. The Mobile Data Association (MDA, 2009a) suggested that

> “While SMS is used for conversational activity, MMS is much more ‘event’ driven, and this was underlined by the seasonal use of both technologies during the festive period... It is clear that MMS and SMS will continue to co-exist and be complementary technologies.”

Fig. 8.3.3 shows the growth in MMS: in December 2008, 56 million picture messages were sent compared to 7,710 million text messages: i.e. 7 for every 1,000 text messages.

Fig. 8.3.3: Growth of picture messaging (MMS): UK: April 2006-December 2008.

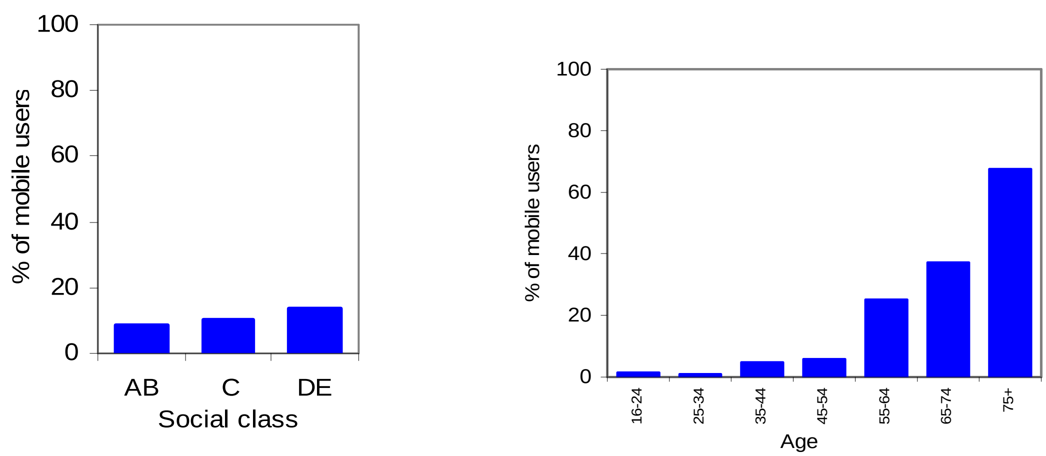


Source: MDA (2009b)

Mobiles are generally used to strengthen existing ties, i.e. create the ‘social solidarity effect’ defined in Chapter 5. “Mobile devices do not enable more social relations but more intensive relations with already existing social contacts” (Vincent & Harper, 2003 p.3), especially for children and teenagers (Harper, 2003; Castells et al, 2007, pp.153, 181 & 249). According to Koskinen (2008), multimedia messaging “almost exclusively takes place in a network of strong relationships” and is used by couples to maintain co-presence. Consequently, the use model focuses on interaction with the agents’ personal network, those within the social reach of 15.

Dutton et al (2009, p.11) reported that internet users “made more use” of their mobiles than non-internet users, suggesting that digital literacy might be important, as noted in Section 2. Efficient texting does require practice and use of more sophisticated features certainly requires familiarity with digital devices i.e. ‘digital literacy’. While mobiles enable people to do more than just make voice calls, two-thirds of mobile users do not use the ‘advanced features’ such as sending photos (ONS, 2008d). Even texting is not done by all mobile users. While texting is a boon for those with poor hearing, it has been of little use to those with poor vision (Goggin, 2006, pp.89-103). It is therefore not surprising that in spring 2008, just over a half of mobile users were not daily texters and indeed, a fifth of UK adults reported that they never used text messaging (Ofcom, 2008b, p.305). Furthermore, in late 2007, 11 percent of mobile users reported that they had no interest in texting (Ofcom, 2008a). This varied a little by class but rose sharply with age (Fig. 8.3.4). Thus digital literacy threshold for texting is set at the initial average score of 1 (compared to 0.5 for adoption). This threshold was, on average, exceeded by DEs by 2002 and by those aged 75 by 2007.

Fig. 8.3.4: Mobile users not interested in texting by class and age: 2007.



Source: Ofcom (2008a)

As in Chapter 6, the model of use focuses on links. As noted in Section 1, almost everyone had either a fixed line phone or a mobile, so mobile users could make voice calls to all their personal network. On this basis, the growth in potential links is simply the growth in adoption: the potential links from mobiles trebled between 1998 and 2007. However, the data on calls starts only in 2002, when according to the model, 63 percent of agents had mobiles. As this had risen to 87 percent by 2007, then calls would have risen by 40 percent (87% / 63%).

However, the increase in mobile calls over this period has been driven by mobile-to-mobile communication, and mobile-to-mobile voice calls increased by 60 percent (Fig. 8.3.1). The model replicates this increase: mobile-to-mobile links increase by two-thirds between 2002 and 2007, with average mobile links per agent rising from 3 to 5 (shown in row 5 of Table 8.3.1).

Unlike voice calls, texting can be carried out only between mobile users able to text. The first full year for which there is data on the number of texts sent is 2000. Between 2000 and 2007, the number of texts increased ninefold (see Fig 8.3.2 above). According to the model, in 2000 49 percent of the agents had mobiles (row 1 of Table 8.3.1), of whom 70 percent were texters (row 6), of whom, in turn, 91 percent had text-using friends in their personal network (row 7). So overall, about a third of all agents were texters (row 9) and these had on average three texting friends (row 8). Thus in 2000, there was on average 1 text link per agent (row 10). By 2007, all these figures had increased (as shown in the last column of Table 8.3.1) giving an average of 3 text links per agent, treble the level of 2000. Given the observed ninefold increase, the number of texts sent per link must also have trebled.

Table 8.3.1: Model results: mobile links: 1998-2007.

Row		**1998**	**2000**	**2002**	**2007**
1	*% with mobiles*	*27*	*49*	*63*	*84*
2	*% of mobile users with mobile-using friends*	*86*	*96*	*99*	*100*
3	With average no. of mobile-using friends	2.7	3.9	4.7	6.0
4	*% of all with mobile-using friends (1)*	*23*	*47*	*62*	*84*
5	Average no. of mobile links per agent (2)	0.6	1.9	3.0	5.1
6	*% with mobiles able to text*	*65*	*70*	*71*	*75*
7	*% of texters with text-using friends*	*76*	*91*	*96*	*99*
8	With average no. of text-using friends	2.2	3.1	3.6	4.7
9	*% of all with text-using friends (3)*	*14*	*31*	*43*	*62*
10	Average no. of texting links per agent (4)	0.3	1.0	1.6	2.9

(1) Row 4 = row 1 x row 2 (2) Row 5 = row 6 x row 7
(3) Row 9 = row 1 x row 6 x row 7 (4) Row 10 = row 8 x row 9

Internet

The focus of this study is social person-to-person communication and the internet now provides a range of suitable communication modes: email, chat rooms, forums, mailing lists, instant messaging, blogs, social network sites, and internet mediated phone calls. (Work orientated activities are not covered here.)

Each mode has a different history and different characteristics. Each is now considered briefly in turn.

- Email provides one-to-one or one-to-few, asynchronous communication. The first email was sent in 1971 (Cummings et al, 2006, p.266) and by the 1980s, was in use in some organisations, especially academia (Simon, 1987; Batty, 1997). Thus email can be taken to be the initial method of internet communication.
- Chat rooms – one-to-few and synchronous – plus forums and mailing lists – one-to-many and asynchronous – grew out of the bulletin boards of the 1970s and Usenet groups of the 1980s (Kitchen, 1998, p.32). Arguably, these are not forms of personal communication, yet they do enable people do get to know others (Di Gennaro & Dutton, 2007).
- Instant messaging (IM) provides one-to-one synchronous communication. The modern version appeared in 1996 (Cummings et al, 2006, p.266).
- A blog, short for "weblog", is a journal or newsletter that is frequently updated and is for public consumption (Hodkinson, 2007; Ofcom, 2008b, p.350). Blogs thus provide asynchronous, one-to-many communication. At its simplest blogging requires only access to a web page: but in the mid-1990s web page creation was restricted to the technically competent (see for example, Savola, 1995). Although likened to broadcasting, often the audience is actually friends and family (Nardi et al, 2004). However, there is contradictory evidence as to whether or not blogging generates friendships (Pickard, 2009; Di Gennaro & Dutton, 2007). The arrival of *Twitter* in 2006 introduced "micro-blogs" (Lenhart & Fox, 2009) which, it could be argued, are more like social network sites.
- Social network sites (SNS) combine features seen in forums and chatrooms in the

late 1990s (Ofcom, 2008d, p.10). According to Boyd & Ellison (2008) SNS differ from forums in that SNS are "structured as personal (or 'egocentric') networks" rather than by topic. They defined SNS as:

> "web-based services that allow individuals to (1) construct a public or semi-public profile within a bounded system, (2) articulate a list of other users with whom they share a connection, and (3) view and traverse their list of connections and those made by others in the system".

On this definition the first SNS was launched in 1997 (Boyd & Ellison, 2008). But it was 2005 before Ofcom noted a "rapid" growth in the popularity of SNS in the UK (Ofcom, 2006, p.172), since when their popularity has mushroomed. In 2009, the average *Facebook* user spent 6 hours a month on the site (Ofcom, 2008d; Ofcom, 2009b, pp.289-9).

- Voice-over-internet (VoIP) is a way of using the internet to make phone calls and is therefore a direct substitute for fixed line and mobile phones. By adding a webcam, video calls can be made. They are one-to-one and synchronous.

Academics have been concerned that the internet is not good for social cohesion: for example Kraut et al (1998) – albeit later retracted (Kraut et al, 2002) – and Nie & Hillygus (2002) – although dismissed by Boase (2008) on methodological grounds. Rather there is a growing body of literature that suggests that those online are more sociable than those who are offline (such as Katz & Rice (2002, pp.263-4), Di Gennaro & Dutton (2007), Wang & Wellman (2009) and Thelwall (2008)) and that those who are not online are more likely to be lonely than those who are online (Dutton et al, 2009, p.5).

Unlike with mobiles, where there is data on the minutes of voice calls or the number of text messages, there appears to be no time series available recording the number of emails, let alone IM interactions. Reliance therefore has to be placed on surveys, which are often ad hoc.

"Internet communication has not replaced other modes of communication" (Kennedy & Wellman, 2007; Boase et al, 2006; Katz & Rice, 2002, pp.228-235). Tillema et al (2008) found that the frequency of face-to-face communication was "positively correlated with that for electronic communication". Internet use and mobile ownership have been found to be "highly related" (Katz & Rice, 2002, pp.252-254; Dutton & Helsper, 2007, p.20). Licoppe & Smoreda (2006) pointed out that email is 'cheaper' in time and money, making "it possible to have frequent small exchanges". As noted, use of SMS and MMS in the UK continues to rise despite the availability of email and IM (Ofcom, 2008b, p.305). Some have suggested that email has reduced telephone and face-to face contact (in the US, Quan-Haase & Wellman, 2002; Boneva et al, 2001; and in the UK, Stoneman, 2008). Not only do internet-based communications compete with face-to-face communication, mail and phones, but also with one another. For instance, blogging has been found to reduce email (Nardi et al, 2004) and children have been found to prefer IM to email (Ofcom, 2008b, pp.129 & 345). Stern (2008) found that it was internet proficiency rather than merely access to the internet that determined the effect on the use of alternative communication modes: for more experienced users there was a reduction in both face-to-face interaction and telephone use. Thus in general, the complementarity effect seems to outweigh the substitution effect, either of other modes of communication or of travel.

Stoneman (2008) suggested that the internet "simply integrates into people's life (sic) without radically altering it for better or for worse" and that

> "internet usage is simply adopted to facilitate already existing practices. The adoption itself does not lead to individuals transforming their patterns of thought or behaviour; it simply makes existing practices more convenient to perform (for example, online shopping or searching for news articles)."

In *Kids will always be Kids*, Harper and I argued much the same in the context of mobile phones (Harper & Hamill, 2005). This, according to Brynin & Kraut (2006, p.6) is a narrow view of the impact of technology in which people do the same sort of things in new ways. Stoneman (2008) suggested that the impact of the internet will change as people become more proficient users, and substitution effects may take time to evolve.

But Brynin & Kraut (2006, pp.4 & 6) argued that the internet could result in "qualitative changes in daily life" in which people accomplish new goals.

Skills

Although most internet users use email, use of the other internet communication modes is less common as shown by Tables 8.3.2 and 8.3.3. But some of the findings reported in these tables do look questionable: do 1 in 5 really write a blog or maintain their own website as suggested in Table 8.3.2? Maybe some of the respondents meant they commented on a blog or newspaper article? Another source, shown in the third column, suggested only 1 in 5 even read blogs. But it does seem likely that by 2008, about 9 out of 10 internet users used email but half did not use "advanced services" such as chat rooms, VoIP and SNS. Use of all types of internet communication declines with age but there appears to be no variation by class.

Table 8.3.2: Use of internet for communication: 2005-2009.

Percent	2005	2008	2009	
	Current users over 14	Recent users	Current users over 14	"Retired" current users
Send email with attachment	66		74	67
IM	56	29	64	35
Social networking sites			49	12
Post pictures/photos	18		44	Na
Chat room	26	20	27	6
VoIP	13	10	23	14
Video calls (via webcam)		12		
Reading blogs		21		
Write a blog	17	7	22	11
Maintain personal website	18		20	
None of the above		53		

"Recent" means used in last three months
Sources: 2005 and 2009: Dutton et al (2009, pp21-22, 28). 2008: ONS (2008d).

Table 8.3.3: Non-use of internet for communication by class and age: 2007.

% of those with internet access who never…	All over 15	Class DE	Age		
			16-19	65-74	75+
Send or receive emails	9	13	6	16	19
Use IM or chat rooms	63	57	21	88	100
Maintain website or weblog	79	79	57	92	100
Look at social networking sites	62	57	17	96	100

Source: Ofcom (2008a).

Thus broadly following Helsper (2008, p.11), internet users in Britain in 2008 can be broadly divided into four groups:

- Non-communicators: about 1 in 10;
- Basic communicators, who use only email: around 40 percent;
- Intermediate communicators, who use IM and social network sites: about 40 percent;
- Advanced communicators who write blogs, say 1 in 10.

The internet thus offers a wide range of opportunities for social connectivity. Indeed, Katz & Rice (2002, p.347) argued that it is this variety that makes the internet different: "it supports any network form", one-to-one, one-to-few and one-to-many. Adding this typology to an adaption of Zhao & Elesh's (2008) distinction between social domains, Table 8.3.4 illustrates the possibilities provided by online connectivity: the 'private' domain is akin to home, while 'public' domains are akin to pubs, clubs and societies. None of the older communication modes offered the public domains. Before the internet, to communicate publicly meant travelling to a place outside the home.

Table 8.3.4: Social domains online.

Domain	**Network**	**Online**	
		Synchronous	**Asynchronous**
Private	One-to-one or one-to-few	IM VoIP	Email
Public (restricted to members or open to all)	One-to-few or one-to-many	Chat rooms	Mailing lists Forums Blogs Micro-blogs SNS

Global village

There are two ways personal networks can be extended through internet use.

First, the internet enables people to keep in touch with those with whom contact would have been lost because of the cost and difficulty of maintaining contact by other means. As noted above, having bought the equipment and paid the broadband subscription, using the internet for communication is free at the point of use. By 2007, two-thirds of users of SNS used them to keep in touch with friends and family they rarely saw, and nearly half used them to look up people with whom they had lost contact (Ofcom, 2008d, p.41). Carrasco et al (2008a, 2008b) noted the importance of email for maintaining contacts, especially over larger distances.

Second the internet enables people to create new links by using the public social areas. Wang & Wellman (forthcoming) reported that in 2007 about one-fifth of adult internet users had “virtual only” friends (i.e. those they had never met in person), but on average these had 5 such virtual friends. But such averages hide a large variation, with a few having a very large number of online only friends (ibid). British studies reported that:

- in 2005, about one in five internet users had “met new friends online” (Di Gennaro & Dutton, 2007);
- in 2006, 15 percent of those who used the internet at home used it to meet new people (Ofcom, 2006, p.172);
- in early 2009, “38% of internet users had met someone on the internet that they had not known before” (Dutton et al, 2009, p.5).

Some of these new friends “migrated from online to offline contact”: 15 percent in the US in 2007 (Wang & Wellman, forthcoming) and in the UK, about half of those who had made new friends online had met one offline (Di Gennaro & Dutton, 2007).

The model

The model looks at the links created by communication over the internet.

Based on an "intentional personal network" (described in Chapter 5), agents' initial social reach was set at 30, which, as shown in Fig. 4.1.2 gives an average personal network ranging in size from about 11 to 52 with an average size of about 28.

Overall, three-quarters of internet users in early 2009 considered their internet skills "good or excellent", but this varied from nearly all students to only half of those who were retired (Dutton et al, 2009, p.14). Far fewer were so confident in their social skills such as making friends online (Dutton et al, 2009, p.15). Ability shapes the pattern of use (Di Gennaro and Dutton, 2007) and the impact of the internet on social contacts increases with experience (Stern, 2008; Dutton et al, 2009, p.4). To reflect this, two further digital literacy thresholds are added to the model: 1.5 to use email, and 1.7 to use the advanced features.

'E-friends' are agents with whom contact is maintained through the internet. Agents using email create a group of 'local e-friends' who are within their social reach and also use email. The model assumes that agents keep in contact with these friends if they move beyond the social reach due to socialshifting, i.e. they become 'distant e-friends'. Once agents become advanced users, however, they can find new friends online, within their new virtual reach, which increases as their digital literacy score rises. Thus agents who are online have four basic types of contacts:

- 'offline only', who are within the social reach and are only contacted offline.
- 'local e-friends', who are within the social reach and who are also contacted online.
- 'distant e-friends', who were once within the social reach but are now outside it.
- 'virtual e-friends' who are beyond the social reach but within virtual reach.

These distant and virtual links would not exist were it not for internet communication. (Details in Box 8.3.1.)

Box 8.3.1: Internet use model: e-friends.

Virtual reach = social reach + (digital literacy score – advanced user threshold) x 10.
Social reach = 30
Advanced user threshold = 1.7
Examples:

- If the agent's digital literacy score is 2.1, the maximum score in 1998, then its virtual reach is 30 + (2.1 – 1.7) x 10 = 34.
- By 2007, the maximum social reach is about 2.8 giving a maximum virtual reach of 30 + (2.8 – 1.7) x 10 = 41.

All e-friends within the social reach were counted as local e-friends. By definition, virtual e-friends are beyond the social reach.

To avoid double counting distant e-friends and virtual e-friends: the two sets of e-friends were identified, the lists compared and duplicates removed. If a virtual e-friend is already a distant e-friend, it is counted as a distant e-friend.

Advanced users are only connected with those who can reciprocate links i.e. links are only permitted if their length is less than the virtual reach of both of the agents it links.

The rate of socialshifting is a key determinant of the number of distant e-friends, those with whom contact is maintained despite moving away. Thus two rates of socialshifting were assumed, 5 percent, as for the adoption model, and 20 percent in order to bracket the likely impact. As distant e-friends are created by socialshifting, there are by definition no such friends in the model in 1998. As few people would have had such social links at that time, this initialisation problem is probably not too serious.

Results

The full results are given in Table 8.3.5. According to the model, in 1998, 60 percent of those online used email and 16 percent were advanced users. By 2007, these proportions had increased to 90 percent and 70 percent respectively, broadly in line with some of the findings reported above. As more agents came online and became advanced users, the number with e-friends rose and so did the number of e-friends each had. Thus by 2007, those online had on average 1½ more people in their personal networks than those who were not online, due to distant and virtual e-friends.

In 1998, 99 percent of the average personal network had been offline only, but by 2007, over a third involved some online contact and 3 percent were distant and virtual e-friends. Again, following the approach set out in Chapter 6, in 1998, there were 0.15 online links per agent and by 2007, this number had risen more than sixty-fold, to about 11. As noted above, in 1998 there were no distant e-friend links. Virtual e-friend links were rare. By 2007, there were around 0.7 per distant and virtual e-friend links per agent. These are links that would not have existed had there been no communication through the internet

The socialshifting assumption appears to make no difference overall, because although it does increase the proportion with distant e-friends and the number of such friends, the scale is still small. However, this model does not allow for that fact that those who are young are more likely to be online and to socialshift and so may underestimate this effect. This could be investigated in further work. The fact that there were fewer virtual e-friends when socialshifting was higher reflects the fact that there were more distant e-friends. Whether this result is an artefact of the model or a real effect is arguable. In that the number of contacts is limited by time constraints, as discussed in Chapter 2, it may, however, be a reasonable outcome.

The change implied by the model is much less than suggested by a 2006 survey that reported that people in the UK had 54 friends on average compared to 33 two years earlier (Microsoft, 2006). However, the same survey apparently found that "a third of over 65s use instant messenger to contact friends" – a finding completely out of line with the findings from other sources reported above. (It may be that respondents were confusing email and IM.)

Table 8.3.5: Model results: how the internet has changed personal networks: 1998 to 2007.

	1998	2007	
Socialshifting %		***5***	***20***
% agents online	*11*	*59*	*60*
% agents online using email	*60*	*92*	*92*
% of agents online advanced users	*15*	*71*	*71*
Personal networks			
Average PN size of agents offline	28.5	28.2	28.6
Average PN size of agents online	28.4	30.2	30.2
of which			
Offline only	27.0	11.8	11.9
Local e-friends	1.4	17.0	16.8
Distant & virtual e-friends	0.002	1.4	1.5
% distant & virtual e-friends	0.01	4.6	5.0
Average PN size of all agents	28.5	29.4	29.5
% of which			
Offline only		63	63
Local e-friends	0.5	34	34
Distant & virtual e-friends	0.001	3	3
Links			
Local e-friends			
% all agents online and with…			
No local e-friends	5	5	5
With local e-friends	6	54	54
With average no. of e-friends	2.6	18.6	18.4
Average no. of local e-friend links	0.15	10.10	10.00
Distant e-friends			
% all agents online and with…			
No distant e-friends		53	40
With distant e-friends		6	20
With average no. of e-friends		1.2	1.4
Average no. of distant e-friend links		0.07	0.27
Virtual e-friends			
% all agents online and with…			
No virtual e-friends	11	30	32
With virtual e-friends	0.27	30	27
With average no. of e-friends	0.1	2.5	2.3
Av. no. of virtual e-friend links	0.0004	0.75	0.63
Total e-friend links	**0.15**	**10.92**	**10.90**

While mobiles have increased contact within personal networks, the internet has increased both the size and the geographical spread of personal networks. But the larger the personal networks, the higher will be the demand for travel. Urry (2007, p.232; 2003b, 2004a) has argued that the maintenance of weak ties requires occasional face-to-face meetings. But why would people spend their limited time and money on visiting weak ties rather than stronger ones? Nevertheless, internet-based communications are enabling people to keep in touch easily and cheaply over large geographical distances. Mail and phones already permitted contact to be maintained, albeit less conveniently and at greater cost; what is new is the facility to make new contacts online. To the extent that this is increasing the size of personal networks, then the demand to travel will also increase. And this extra travel will further increase the communication to arrange those meetings: see for example, Boneva et al (2001), Stald (2003, p.245) and Hodkinson (2006). Although the CAA's (2009) report referred frequently to people's desire to maintain their 'social networks', there is, however, no reference to the possible impact of the new digital communications on the demand for air travel.

Adams (1999) argued that there is little evidence for making the presumption that

> "people will be content with lives of increasing incongruity of experience - that they will not want to meet and shake hands with the new friends that they meet on the Internet"

Root (2000, p.452) noted that "many claims have been made that new information technologies will limit the need for travel but these have not been upheld". And Woolgar (2002, pp.16-19) asserted that "virtual technologies supplement rather than substitute for real activities" and "the more virtual, the more real": the introduction and use of new 'virtual' technologies can actually stimulate more of the corresponding 'real' activity". More recently Larsen et al (2006, p.74) told the DfT that "so far there are good reasons to believe that physical travel will continue its growing significance... in relationship to …family life and emerging forms of friendship."

8.4 The Future?

McLuhan (1964/2003, p.294) warned that prophecies "assume a stable framework of fact" and that such prophecies are usually, as a result, wrong. Nevertheless, policy-makers and others will always want to know 'what if…?' So this Section reports what this model implies for the future, focusing on 2016 and 2021 so as to be able to compare the forecasts with those in *Digital Britain* (BIS, 2009).

To look forward it is necessary to make assumptions about whether trends continue and if so, at what rate. The trends described above are assumed to continue with two exceptions:

- income growth is set at the average long-term rate of 2 percent a year (instead of 2.4 percent);
- there are assumed to be no further price falls in mobiles and computers.

Mobiles

The results for mobiles are shown in Table 8.4.1. By 2016 the adoption of mobiles will have reached saturation at almost 95 percent. The number of mobile links, and thus voice calls from mobiles, will rise by about a quarter between 2007 and 2016. But there will be little further growth in adoption or voice calls beyond then. However, the proportion of texters will still be rising; thus the number of text links will increase by almost a half by 2016 and by 2021 will be almost two-thirds above the 2007 level, implying significant further increases in text messaging.

Table 8.4.1: Model results: forecast change in adoption of mobiles and texting: 2007-2021.

Row		**2007**	**2016**	**2021**
1	*% with mobiles*	*84*	*95*	*97*
2	*% of mobile users with mobile-using friends*	*100*	*100*	*100*
3	With average no. of mobile-using friends	6.0	6.9	7.0
4	*% of all with mobile-using friends (1)*	*84*	*95*	*97*
5	Average no. of mobile links per agent (2)	5.1	6.5	6.8
6	*% with mobiles able to text*	*75*	*80*	*83*
7	*% of texters with text-using friends*	*99*	*100*	*100*
8	With average no. of text-using friends	4.7	5.6	5.9
9	*% of all with text-using friends (3)*	*63*	*77*	*81*
10	Average no. of texting links per agent (4)	2.9	4.3	4.7

(1) Row 4 = row 1 x row 2
(2) Row 5 = row 6 x row 7
(3) Row 9 = row 1 x row 6 x row 7
(4) Row 10 = row 8 x row 9

Internet

The results for the internet are shown in Table 8.4.2.

- By 2016, 4 out of 5 will be online and of these, 95 percent will use email and about 80 percent will be advanced users. On average, those online will have personal networks that are 10 percent larger than those who are not online i.e. with an extra 3 people. Overall, two-thirds of personal networks will be at least partially online. Distant or virtual e-friends will account for 8 percent of the average personal network. The number of online links per agent will have doubled since 2007, from 10 to 20.

- By 2021, 5 out of 6 will be online and of these, almost all will use email and about 85 percent will be advanced users. On average, personal networks will be about 15 percent larger i.e. with an extra 4 people. Overall, three-quarters of personal networks will be at least partially online and on average 10 percent of personal networks will be distant or virtual e-friends. The number of online links will have risen by a further 20 percent since 2016, bringing it roughly 2½ times the number in 2007.

Again, the socialshifting assumption makes little difference overall, because higher mobility means that some distant e-friends are substituted for virtual-e-friends.

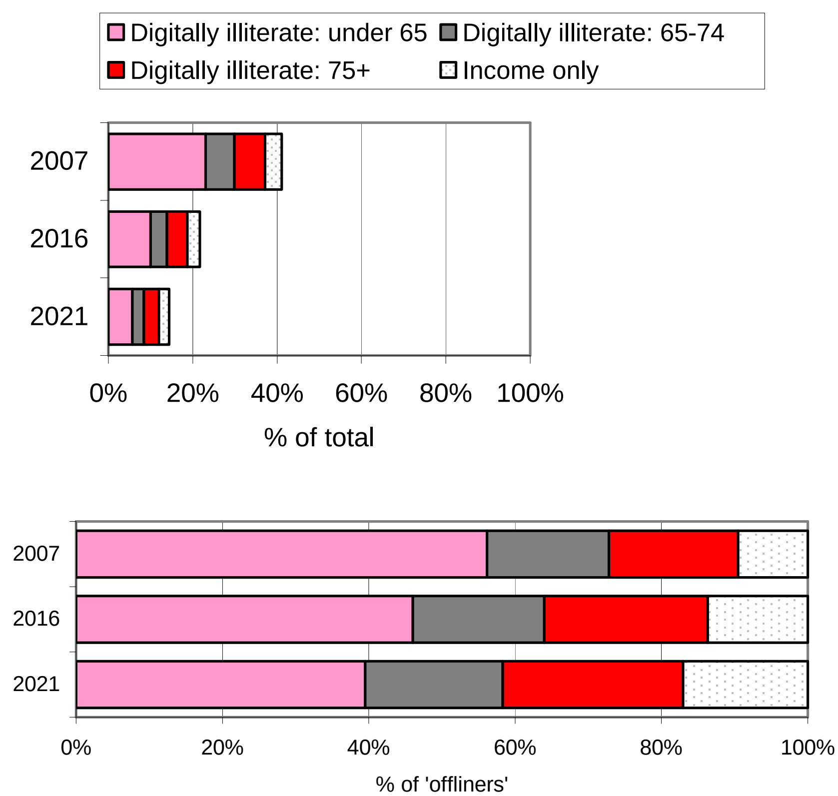
Table 8.4.2: Model results: how the internet might further reconfigure personal networks: 2007-2021.

	2007		2016		2021	
Social shifiting % pa	***5***	***20***	***5***	***20***	***5***	***20***
% online	*59*	*60*	*79*	*79*	*86*	*86*
% agents online using email	*92*	*92*	*95*	*95*	*96*	*97*
% of agents online advanced users	*71*	*71*	*81*	*82*	*85*	*85*
Personal networks						
Average PN size of agents offline	28	29	28	29	28	28
Average PN size of agents online	30	30	31	32	32	33
of which						
Offline only	12	12	7	7	5	5
Local e-friends	17	17	22	22	24	24
Distant & virtual e-friends	1	2	3	3	3	4
% distant & virtual e-friends	*5*	*5*	*9*	*10*	*10*	*12*
Average PN size of all agents	29	30	31	31	31	32
% of which						
Offline only	*63*	*63*	*36*	*31*	*26*	*25*
Local e-friends	*34*	*34*	*57*	*61*	*65*	*65*
Distant & virtual e-friends	*3*	*3*	*7*	*9*	*9*	*11*
Links						
Local e-friends						
% all agents online and with…						
No local e-friends	*5*	*5*	*4*	*4*	*3*	*3*
With local e-friends	*54*	*54*	*75*	*75*	*83*	*83*
With average no. of e-friends	19	18	23	23	25	25
Average no. of local e-friend links	10.1	10.0	17.5	17.5	20.6	20.7
Distant e-friends						
% all agents online and with…						
No distant e-friends	*53*	*40*	*58*	*30*	*56*	*25*
With distant e-friends	*6*	*20*	*21*	*49*	*30*	*61*
With average no. of e-friends	1	1	1	2	1	2
Average no. of distant e-friend links	0.1	0.3	0.3	1.0	0.4	1.5
Virtual e-friends						
% all agents online and with…						
No virtual e-friends	*30*	*32*	*15*	*15*	*13*	*13*
With virtual e-friends	*30*	*27*	*64*	*64*	*73*	*73*
With average no. of e-friends	3	2	3	3	4	3
Av. no. of virtual e-friend links	0.8	0.6	2.2	1.9	2.8	2.4
Total e-friend links	**10.9**	**10.9**	**20.0**	**20.4**	**23.8**	**24.6**

There will, however, be significant minorities still offline in 2016, and even in 2021. The overall proportion of 'offliners' will halve from around 40 percent in 2007 to 25 percent by 2016, and fall to 17 percent by 2021. Even in 2021, lack of digital literacy will remain the most important cause for being offline, being a factor in 5 out of 6 cases. Furthermore, not all the digitally illiterate offliners will be aged 65 or over: digital illiteracy will remain a problem among younger people too. (Details in Fig. 8.4.1.) Nevertheless, age is significant: the model suggests that 14 percent of those aged 55-64, 25 percent of those aged 65-74 and 40 percent of those aged 75 and over will be offline in 2021. Lack of income will account for 1 in 6 offliners in 2021: half of those in the bottom decile will be offline. These results are broadly similar to those reported by Morris (2009, p.35):

> "if all other factors remain constant, the overall proportion of the 16+ population who are digitally excluded would reduce from 29% in 2009 to 15% in 2021, due to demographic change. In this scenario, by 2021 digital exclusion will continue to be a significant issue for those over 65, with 52 percent still experiencing digital exclusion".

Fig. 8.4.1: Analysis of 'offliners': 2007, 2016 and 2021.
Reason for being offline:



8.5. Summary and Conclusion

Drawing on the models developed earlier in the thesis, this Chapter has presented a model that reproduces both the adoption and use of mobiles and the internet for communication since 1998 by varying the parameters to reflect the different communication modes.

Table 8.5.1: Summary of the model.

Target	Adoption and use of mobiles and internet: 1998-2021	
Agents	Individuals	
Agents		
	Attributes	Dynamics
Location	Grouped by social class	
Demographic	Age	Birth and death
Socio-economic	Class Income Economic status	 Income grows Retirement
Skills	Digital literacy	Personal and social network influences
Personal network Social network effect	Social reach = 15 or 30	Socialshifting Yes

The model suggests that the adoption and use of both mobiles and the internet can be attributed to the spread of digital literacy skills. These skills spread both through the generation effect, as the older generations are replaced by younger more digitally literate generations, and through personal and social networks. It also suggests that the age and class distribution of digital literacy created a core group of internet adopters who facilitated the spread of the internet through network effects, in other words, created a critical mass.

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.

Table 8.5.2 summarises the results for mobiles.

Table 8.5.2: Summary of results: mobiles

Target	Adoption and use of mobiles: 1998-2021	
Adoption		
Key factors	Affordability	
Use		
Communication effects		
Social solidarity?	Yes	Strong
Communication substitution?	Yes	Weak
New practices?	Yes	
‘Global village’:		
- maintain contact?	Yes	Weak
- new friends?	No	
Travel effects		
Complementary increase?	Yes	
Travel communications?	Yes	Strong
Substitution reduction?	Yes	Limited

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 will increase 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, represented an extra 4 people, by 2021.

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, who, as shown in Box 8.2.1, will account for 11 percent of the population aged 10 and over.

Table 8.5.3 summarises the results for internet communication.

Table 8.5.3: Summary of results: internet communication.

Target	Adoption and use of the internet: 1998-2021	
Adoption		
Key factors	Digital literacy and personal and social networks	
Use		
Communication effects		
Social solidarity?	Yes	Strong
Communication substitution?	Yes	Weak
New practices?	Yes	Strong
‘Global village’:		
- maintain contact?	Yes	Strong
- new friends?	Yes	Only mode to allow this
Travel effects		
Complementary increase?	Yes	
Travel communications?	Yes	
Substitution reduction?	Yes	Limited

The impact of this digital communication revolution is discussed further in Chapter 9.

Further work

Di Gennaro & Dutton (2007) argued that the internet has many uses and more subtle analysis is needed. The study presented here has been broad brush: more detailed analysis could be undertaken. For instance: the links between youth, mobility and maintaining links over distance (Section 3) and distant and virtual e-friends (Section 4) could be more explicitly developed, and as could the difference between weak and strong links.

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 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.

Acronyms

BERR: Department for Business Enterprise & Regulatory Reform
BIS: Department for Business Innovation and Skills
CAA: Civil Aviation Authority
CSO: Central Statistical Office
DCMS: Department for Culture, Media & Sport
DE: Department of Employment
DfES: Department for Education and Skills
DfT: Department for Transport
DTI: Department of Trade and Industry
DTp: Department of Transport
DWP: Department of Work & Pensions
GRO: General Register Office
HMSO: Her Majesty's Stationery Office
IM: Instant Messaging
MDA: Mobile Data Association
MMS: multimedia messaging
NTS: National Travel Survey
Ofcom: Office of Communications
Oftel: Office of Telecommunications
ONS: Office for National Statistics
OPCS: Office of Population, Censuses and Surveys
ORR: Office of Rail Regulator
Postcomm: Postal Services Commission
PAC: Public Accounts Committee
PAYG: pay-as-you-go (for mobile phones)
PN: personal network
sd: standard deviation
SMS: text messaging
SNS: social network sites
RPI: retail price index
TSO: The Stationery Office
VoIP: voice-over-internet

Glossary

*Terms marked * are those specific to this thesis.*

Agent-based model: a computer program that creates a world of heterogeneous agents in which each agent interacts with other agents and with the environment.

Assortativity: see **Positive assortativity by degree of connectivity.**

Clustering coefficient: the extent to which the nodes connected to a given node are in turn linked to each other (Scott 1991, p.74). It is measured by the ratio of the actual number of links to the maximum possible number of links.

Communication substitution effect*: a new communication mode results in reductions in use of older communication modes.

Complementary travel effect*: more communication results in more travel.

Degree of connectivity: the number of links to or from a node.

Degree of separation: the shortest **path** between any two nodes.

Density – see **Whole network density**.

Directed link: a link from node A to node B counts as one link and from node B to node A as another (cf **undirected link**). If there are n nodes in a network, there are $n(n-1)$ directed links.

e-friends*:

- ‘Local’, who are within the **social reach** and who are also contacted online.
- ‘Distant e-friends’, who were once within the **social reach** but are now outside it.
- ‘Virtual e-friends’ who are beyond the **social reach** but within virtual reach.

Epistlers*: those who were literate, had access to the mail system and could afford to use these services.

Gini coefficient: measures the degree of inequality in income distributions: the lower the coefficient, the more equal the distribution. (See Box 2.2.1.)

Global village effect*: new communications technologies increase the geographical spread of contacts (named after McLuhan).

Income elasticity: measures the extent to which demand changes when incomes change. The demand for a good usually rises when incomes rise as so it is usually positive. If the income elasticity is less than 1, the good is said to be a necessity: if more than 1, a luxury.

Mobiles: mobile communication devices, usually phones.

NetLogo: the agent-based simulation environment used in this thesis (Wilensky, 1999).

New practices*: new behaviours that arise as a result of a new communication mode.

Path length: the distance between a pair of nodes measured by the number of links between the pair, given that any node or link can only appear once in each path (Scott, 1991, p.71).

Personal network: all those who have ties with a specified individual, sometimes called ego-centric network.

Positive assortativity by degree of connectivity: those with large personal networks tend to know others with large personal networks.

Price elasticity: measures the extent to which demand changes when prices change.

- The own-price elasticity measures the extent to which the demand for a good changes when its price changes.
- Cross-price elasticities measure the extent to which the demand for one good changes when the price of another good changes.

Reach: see **Social reach**.

Real terms: means adjusted for inflation. If income or expenditure rises faster than inflation, then they have risen in real terms.

Size (of a network): the number of nodes or links (Calderelli, 2005, p.254; Scott, 1991, pp.78 & 105).

Social reach*: the radius of the circle that determines the size of the personal network.

Socialshift*: the percentage of agents who move the minimum possible each time step.

Social solidarity effect*: a new communication mode is used to send messages to those in the agent's personal network.

Stylised fact: a “simplified presentation of an empirical finding” (Gilbert, 2007, p.127), usually at macro level.

Travel communications effect*: more travel results in more communication.

Travelling epistlers*: epistlers who also had access to the rail network.

Travel substitution effect*: better, easier or cheaper communication modes reduce the need to travel.

Undirected link: a link between nodes A and B is counted as just one link (cf **directed link**). If there are n nodes in a network, there are $n(n - 1) / 2$ undirected links.

Whole network density: the ratio of the actual number of links in a network to the total possible.

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