The Economics of Broadband in Ireland:

Country Endowments, Telecommunications Capital Stock, and Household Adoption Decisions

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By

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Contents

List of Figures

List of Tables

Abstract

Economic growth is central to improved living standards, in turn; technological change and the spread of economically useful knowledge are essential inputs for sustainable growth. Broadband matters for long-run growth because it reduces the cost of knowledge search and increases the rate of knowledge production. Ireland lags the OECD across a range of broadband indicators including, penetration; availability; price; and speed. What explains these disappointing broadband outcomes and why is Ireland different? Are the differences rooted in policy, or are there specific geographic and demographic reasons? Is privatisation to blame, or do the causes predate privatisation? Do consumer characteristics (income, education, preferences) explain Ireland's outcomes, or are the differences driven more by investment and supply-side constraints? The different answers to these questions will have distinct implications for policy. To investigate these questions I adopt a methodologically pluralistic approach conducting three empirical studies with different data sets and methodologies. The first study uses international data and OLS regression techniques to examine the various effects of a set of country endowments. These are each expected to provide differential advantages to countries, to be unrelated to policy, and to help explain international variation in broadband subscription. The derived model explains over 85 per cent of international variation. The results suggest broadband penetration is positively influenced by population density, the diffusion of vintage technologies, and the population's educational attainment. Using the model estimates I construct an international league table of broadband efficiency and confirm Ireland is indeed underperforming compared to the OECD. The second study uses the Perpetual Inventory Method and data from government agencies to investigate the development of Ireland's pre broadband telecommunications infrastructure and the year-on-year growth in the telephone capital stock. The telephone capital stock is the infrastructure enabling the majority of fixed-line broadband connections in Ireland. I find investment was stop-start in the twentieth century. There is little evidence telecommunications infrastructure was a consistent priority of government. The third study uses sample data from the 2006 Census of Population to estimate a logit model of household broadband adoption decisions in Ireland. The derived estimates show that odds of broadband adoption are influenced by variables related to wealth and variables related to location. The results suggest geographic differences in broadband adoption are driven more by differences in availability, than by differences in consumer preference and awareness. Overall I find little evidence that the personal characteristics of Irish consumers are responsible for Ireland's poor broadband outcomes. Ireland's underperformance is best understood as a function of weak competition and low levels of investment, especially in low density areas where the commercial case for network infrastructure provision is particularly unattractive.

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I dedicate this thesis to my grandmother and to the memory of my godparents.

Author’s Declaration

I declare that this thesis is the product of my work alone and has not been submitted for any other award.

Thomas A. McDonnell

Preface

Ireland compares very badly with the rest of Western Europe across a range of headline broadband indicators including broadband availability, diffusion, price and speed. This striking empirical fact was the original motivation underlying the research contained within this thesis. Why did the rate of broadband diffusion in Ireland differ so markedly from that of the rest of Western Europe? Are the causes of this difference rooted in policy, or were there specific geographic and demographic reasons that held Ireland back? Is the Eircom privatisation to blame, or do the causes of Ireland's perceived underperformance predate privatisation and the broadband era? Can the particular characteristics of Irish consumers, such as income levels, education and personal preferences explain these differences, or are the differences driven more by levels of investment and supply-side constraints? What do the answers to these questions imply for future broadband policy, and should policymakers even care about the development of the broadband market? Answering these questions was my goal in undertaking this thesis.

The thesis work began on the very same day I first lectured in economics. Given my fear of public speaking the lecture was my main worry on that day. Nevertheless, it is the thesis that has since given me far more sleepless nights. While my enthusiasm for the subject has never flagged, it is the seemingly infinite patience and good humour of my thesis supervisor Dr. Aidan Kane that has kept the research on track. His thorough dissection of earlier drafts has helped shape the work and his insight and expertise has added coherence, logic and clarity to the arguments. The guidance of Professor Michael Cuddy was crucial at an early stage and I was deeply grateful for it.

The economic crash has somewhat discredited mainstream economics. The failures of economic policymaking in Ireland and in other countries will, I hope, encourage the economics profession to re-evaluate some of its core assumptions and shibboleths, and perhaps even rekindle the profession's interest in methodological pluralism and in economic history. The economy is a highly complex and evolving system. Yet there is often little acknowledgement within the profession of the tenuousness or context dependence of some of the empirical claims made.

This concern influenced my methodological approach and is my justification for the decision to approach the puzzle of Ireland’s broadband diffusion using a set of three standalone empirical studies. The first study is a country level macro-analysis of broadband diffusion, the second study is an historical time series of telephone capital stock accumulation, and the third study is a household level micro-analysis of broadband adoption decisions. In addition, I present an exposition of economic growth theory and a review of technology diffusion models, and I also make a case for broadband’s particular relevance to long-run economic growth. This is supplemented by a description of international broadband policy and of broadband market development in Ireland. These reviews supplement and inform the three empirical studies. While the thesis cannot fully explain a phenomenon as complex as Ireland’s broadband market development and outcomes, I believe that it will nevertheless contribute to our collective understanding of Ireland’s broadband puzzle.

Chapter One: Introduction and Overview, Ireland and the Broadband Question

1.1 Introduction

Broadband matters. This work is about the spread or ‘diffusion’ of broadband Internet, the development of Ireland’s broadband market, and the implications for Ireland’s long-run economic growth. Why should economists care about broadband? One of the purposes of economics as a discipline is to explain how societies can sustainably improve the living standards and quality of life of their population. The huge variation in well-being across countries is largely the outcome of long-term differences between countries in terms of economic growth and development. In chapter two I consider what drives economic growth in the long-term. Most conventional growth theories regard advances in technology and economically useful knowledge as essential inputs for long-run economic growth. The production and diffusion of knowledge is itself a function of the cost of knowledge. The main reason broadband matters for growth is that high speed access to the Internet dramatically reduces the cost of obtaining knowledge. In particular, access to the World Wide Web assists learning, knowledge search and the spread of new ideas. Ireland’s broadband story is of particular interest. As discussed in chapter three, despite being one of the highest income countries in the world, Ireland compares poorly with other advanced economies across a range of broadband indicators. Yet Ireland’s relatively poor broadband outcomes need not imply underperformance. Unless we have a benchmark or expected level of performance it is impossible to determine whether a particular outcome actually represents underperformance.

In order to determine whether Ireland is underperforming I conduct a cross-country study of international broadband penetration outcomes. The empirical strategy and the model estimates are described in chapter four. The estimates are used to establish a benchmark level of performance for Ireland. I find that Ireland is indeed underperforming given its particular set of geographic, demographic and economic endowments and that Ireland’s broadband penetration has been impeded by its low population density; the delayed start to its broadband diffusion process; and its low level of dial-up Internet subscriptions in 2000. Digital Subscriber Line (DSL) technology is the dominant broadband platform in most OECD countries. DSL uses the infrastructure of the telephone network. One argument is that a main cause of Ireland’s weak broadband outcomes is the low levels of investment made to upgrade the telephone network infrastructure to provide broadband services. Yet the initial size and quality of the telephone network infrastructure at the start of the broadband era may also have influenced broadband diffusion and quality. In chapter five I investigate the development of Ireland's pre broadband telephone network infrastructure by constructing a time series of capital stock estimates for the seventy five year period leading up to the telephone network's privatisation at the end of the twentieth century. I find that annual investment in the network infrastructure during this period was inconsistent and 'stop-start' from year-to-year. The demand for telephone landlines heavily outstripped the supply of landlines for much of the twentieth century and the overall quality of service was poor by Western European standards. Ireland's poor broadband outcomes are therefore very much in keeping with an historical trend of underperforming telecommunications outcomes. The causes underlying the broadband adoption patterns of Irish householders' represent another important aspect of Ireland's broadband diffusion story. In order to explain differences in broadband adoption outcomes for Irish households I develop an empirical model of broadband adoption in chapter six. I find that the odds of broadband adoption are influenced by the respondent householder's level of wealth and the respondent's geographic location. Geographic differences in broadband adoption do not appear to be driven by differences in the preferences and awareness of Irish householders. The importance of geographic location appears to be related to the lack of broadband availability in rural and low density areas.

Ireland's relatively poor broadband performance should be understood as the outcome of a number of interrelating factors. Ireland's relatively dispersed and low density population means higher average fixed costs for service provision. This makes Ireland less commercially attractive as a location for investment than other OECD countries. Path dependence also matters. Countries that fall behind tend to stay behind. In addition, relatively weak inter-platform competition in Ireland from the competitor cable network reduced the need for the dominant market player Eircom to invest in upgrading the quality and size of its broadband network. Eircom's ability to invest was constrained in any event following a pair of highly leveraged buy-outs which loaded the company down with large amounts of debt. I find little evidence that the particular characteristics of Irish householders (e.g. income, wealth, education, preferences) can explain Ireland's lagging of the OECD.

The market for next generation broadband is likely to remain in flux for the next few years, due to fast moving changes in technology. Despite past failures there is as yet no clear market failure for next generation broadband in Ireland. For example, the competitor cable network operator is making substantial investments in next-generation infrastructure, suggesting greater competition in the future. There is certainly a case for targeted direct government intervention in the event of future market failure. However, the case for regulatory support for intra-platform competition in the DSL market is less clear due to the negative implications for long-term investment in the network infrastructure. Finally, there is evidence that Ireland's underperformance is location specific. Subsidising activity that would happen anyway amounts to a deadweight loss and a waste of limited resources. Therefore any direct government investment or fiscal support should be limited to those geographic locations where there is clear evidence of market failure.

1.2 The Broadband Problem

The origins of Internet technology can be traced to the introduction of packet switching (Kurose and Ross, 2009; Living Internet, 2010). Packet switching allowed chunks of data to be sent to different computers without first passing through a central mainframe (Roberts, 1978). This made it possible for a data system to use a single communications link to communicate with multiple transceivers at the same time (Kurose and Ross, 2009). The Internet is a network of computers communicating with each other using a particular communications protocol known as the Internet protocol (Kahn and Cerf, 1999). Broadband Internet is a relative term and has no universally agreed definition. For example, the OECD (2006) defined a broadband connection as Internet access with a minimum data transfer rate for downloading information equal to or faster than 256kbits per second, whereas the United States Federal Communications Commission (FCC) does not define minimum thresholds. The FCC simply defines broadband access as always-on Internet access that is faster than the traditional dial-up access (FCC, 2011). Throughout this work I use the term broadband as shorthand to mean high bandwidth Internet access with sufficient transmission speed to use advanced Internet applications, without constraint, and with "always-on" functionality.

Knowledge is central to sustainable long-run economic growth and most conventional growth theories emphasise the importance of new ideas within the process of long-term economic change (Aghion and Howitt, 2009). Broadband is important for economic growth because it provides fast, reliable, and low cost access to the World Wide Web (Web). Richard Whitt (2009, p.419) points out that "in a rapidly evolving global marketplace, new ideas and technologies are the fodder that fuels a nation's economic growth". New ideas almost always originate, in one form or another, from the ideas of other people. Certain human environments such as cities (Lucas, 1988) and the Web (Johnson, 2010) are more conducive to knowledge and idea spillover than other environments. This is because they provide physical or virtual proximity to other people and therefore to other people's ideas. The Web is a medium which allows the user access to a vast amount of information provided by other people and where information flows, and is stored, recycled and replicated. However, we cannot consider the benefits of direct investment in broadband infrastructure in isolation from the substantial costs associated with infrastructure provision and other opportunity costs. Policy decisions must always be judged against their opportunity cost and economic policymakers should allocate their limited resources to achieve the largest possible increase in the economy's capacity to produce goods and services, and maximise social benefit in a sustainable way (Nafziger, 2006). Is broadband different? While acknowledging opportunity costs there are arguments that the broadband market is qualitatively more important than other markets.

Douglass North (1990) argues that governments should pay serious attention to the economy's institutions. Institutions are the structures, rules and norms that influence economic incentives. A successful economy depends on good institutions to create the right incentives for innovation and knowledge production. One way to incentivise knowledge 'activity' is to reduce the cost of knowledge. Broadband quality access to the Web amounts to a decline in the costs of finding, developing and spreading useful knowledge. Like writing and printing before it, broadband exhibits the characteristics of what Timothy Bresnahan and Manuel Trajtenberg (1995) call transformative and economically pervasive 'General Purpose Technologies'. Broadband's economic impact is not just in the telecommunications industry, but all over the economy, as it enables new business models, processes and services (Economist, 2009). Indeed broadband increases the productivity of those innovation activities, for example R&D, which are themselves intended to generate productivity increases in the economy. The broadband market is therefore of far greater importance for economic development than most other markets. This suggests avoiding broadband market failure should be a policy priority. As Paul Krugman (1999) puts it, "Productivity isn't everything, but in the long run it is almost everything." Philip Weiser quotes the Commissioner of the United States' Federal Communications Commission:

> The normal rule that the development of a technology should be left solely to the marketplace does not apply in the case of broadband, which promises an array of social and economic benefits, ranging from distance learning to telemedicine to public safety to democracy (Weiser, 2008, p.4).

Ireland lags behind many other OECD countries in terms of competitively priced advanced broadband services (Forfás, 2011). By the end of 2010 Ireland ranked 25th out of 34 OECD countries in terms of fixed line broadband penetration. Ireland fares worse than the OECD average in terms of price and speed (OECD, 2011). The minimum monthly price for broadband in September 2010 was the 7th dearest in the OECD, while the average advertised download speed was the 3rd slowest in the OECD (OECD, 2011). Ireland also compares badly in terms of high speed broadband infrastructure. Almost 10 per cent of all broadband lines in the OECD were fibre based by the end of 2010 compared to just 0.5 per cent in Ireland. This provides the context and motivation for the work that follows and in particular for the focus on Ireland. Why has Ireland fallen behind and do Ireland’s weak broadband indicators actually represent broadband market failure?

1.3 Main Contributions and Findings

This section briefly outlines the structure of the work and the main findings. Chapter two establishes the motivation for understanding Ireland’s broadband market development and links long-run economic growth with high speed Internet access. Chapter three then describes the current context for broadband in Ireland including the existing policy and market environment. Ireland trails the OECD across a range of broadband indicators. Nevertheless, Ireland’s relatively poor broadband outcomes should not be conflated with an assumption of broadband policy failure because market development, including the availability and quality of service, is also influenced by a variety of non-policy factors on both the demand side and the supply side. A number of explanations are worth considering. For example, geographic and demographic factors such as low population density and high population dispersion make Ireland a relatively unattractive location for investment in broadband infrastructure (see Faulhaber and Hogendorn, 2001). Lower levels of investment will in turn diminish the extent of broadband availability and reduce the quality of broadband services where they are available. A second consideration is that Ireland’s poor broadband outcomes may partially be path dependent in nature and connected to historical deficiencies in the telecommunications infrastructure. If this is correct, greater infrastructural requirements arising from the need for ‘catch-up’ with other countries, implies additional capital costs simply to provide equivalent broadband services to those available in other countries. Ireland’s delayed broadband take-off may well be a function of relatively high investment costs and/or a relative inability or unwillingness of the network operators to invest in network infrastructure. A third consideration is whether weak competition in the Irish broadband market has kept prices high and quality of service low. If so, the result will be reduced consumer demand and lower penetration rates (Cadman and Dineen, 2006). The epidemic and discrete choice models of technology diffusion (Geroski, 2000; Stoneman, 2001) may also help explain the diffusion of broadband in Ireland. The epidemic model emphasises the importance of awareness for technology diffusion and suggests the possibility that Ireland’s slow rate of diffusion may be caused by a relative lack of consumer awareness of the benefits of Internet technologies. On the other hand, the discrete choice model emphasises that certain characteristics of consumers may influence technology adoption decisions; examples include available financial resources (Flamm, 2005) and level of education (Grosso, 2006). I consider these explanations in the core empirical chapters and examine their validity. The differing answers to these questions will have distinct implications for broadband policy. How can we answer these questions?

In attempting to answer these questions I adopt a pluralistic methodology. Mainstream science often turns out to be wrong and progresses by eliminating error and by generating new insights. In this context it is questionable whether one particular type of experiment or single method should be deemed decisive. How do we know when something is correct and how do we compensate for ideological, methodological, and rhetorical biases? Studying the phenomenon under investigation in a variety of different contexts and in a variety of different ways is one safeguard against such biases. This is what is meant by a methodologically pluralistic approach. Alan Waring (2000, p.2) argues that “it is a mistake to adopt only one approach in some form or another...methodologies are best used in a complementary way”. New insights often only become visible by approaching issues in a cross-disciplinary way or by using different methodologies (Knox, 2004). Paul Feyerabend (1975) argues that: “A scientist who wishes to maximise the empirical content of the work he holds and who wants to understand them...must therefore introduce other views; that is, he must adopt a pluralist methodology.” This pluralistic approach informs the remainder of the work and in reflecting this I conduct three separate empirical studies with distinct empirical strategies and datasets. This approach enables us to consider the central problem of Ireland’s weak broadband outcomes from three distinct perspectives. If we obtain identical or corroborating findings from two or more independent studies we can be much more confident our analysis is accurate. The chosen empirical studies are motivated by the discussions in chapters two and chapter three.

The first empirical study is described in chapter four. An economic model of broadband penetration using international data on cross country broadband subscription rates between

2002 and 2008 is estimated. Using standard OLS regression techniques I model the relationships between broadband penetration and a set of variables identified in the literature for their relevance to broadband penetration (see for example Rappaport, Kridel and Taylor, 2002; and Flamm, 2005). These independent variables are collectively termed as ‘country endowments’. The country endowments are chosen based upon their independence from broadband policy. The resulting OLS model is found to explain 85 per cent of the international variation in broadband penetration in the OECD. The results suggest that Ireland’s relatively low penetration rate is a function of the cumulative effects of relatively low population density, relatively delayed broadband take-off, and relatively low per capita levels of dial-up Internet subscriptions in 2000. The second part of the cross country study draws upon a methodology formulated by Ford, Koutsky and Spiwak (2007 and 2008). As they put it:

> A country with a high subscription rate may actually be a poor performer relative to its endowments, suggesting that the country is not a particularly good example of a successful broadband policy. Or, countries with low subscriptions rates may...have very good broadband policies if their actual rate of subscription exceeds what our model would expect (Ford, Koutsky and Spiwak, 2007, p.13).

I use the estimated coefficient estimates for the country endowments to construct a league table of OECD countries and rank country performance. The league table ranks the efficiency with which OECD countries are transforming their country endowments into successful broadband penetration outcomes. I find that Ireland achieves a below average broadband efficiency score (ranking 22nd out of 30 countries) and based on this finding conclude that Ireland is indeed underperforming relative to the OECD.

The chapter four results suggest that broadband diffusion outcomes may be a function of the quality of the pre-broadband telephone network infrastructure. Therefore in chapter five I construct a time series of annual capital stock estimates for Ireland’s telephone network infrastructure between 1922 and 1997. This was the period when the telephone network was under Irish state ownership. I construct the capital stock estimates from over sixty years of data obtained from Irish government departments using a version of the Perpetual Inventory Method (PIM). The PIM was first developed by Raymond Goldsmith (1951) and is useful because it permits an analysis of the composition and age distribution of the capital stock as it evolves over time, and also because it permits cross-country comparison (OECD, 2001a). The capital stock estimates show that the state-owned telephone network grew at an uneven pace between Irish independence in 1922 and full privatization of the network in 1999. The capital stock measured in constant 2000 prices is estimated to have been £25.9 million in

1922 and £1.5 billion in 1997. Annual investment peaked in the early 1980s. Waiting lists for a telephone landline had reached eighteen months by the 1970s, and until the 1980s, supply was insufficient to meet residential demand for a telephone subscription. Overall the estimates show that the development of the telephone network was 'stop-start' with investment levels highly dependent on the underlying strength of the economy. Ireland's broadband experience in the twenty first century is therefore consistent with a long term trend of underdeveloped telecommunications infrastructure.

In chapter six I investigate whether the characteristics of Irish householders can help explain Ireland's apparent broadband underperformance. I use anonymised sample data from Ireland's 2006 census of population to estimate a discrete choice logit model of Irish householder's broadband adoption decisions. The model design draws on Lancaster's hedonic demand theory (1966) and on the probit model of technology diffusion (Geroski, 2000; Stoneman, 2001). There are a number of requirements for a consciously made adoption decision to occur. These requirements include awareness; capacity, and an expected net benefit on the part of the consumer. Adoption is also contingent upon broadband's availability. My expectation is that differences in the characteristics of individuals will explain part of the variation in Internet adoption decisions and that decision makers with different characteristics will have different odds of adoption at any given time. The results of the estimated logit model confirm that a number of householder characteristics influence the broadband adoption decision. In particular, respondents from the managerial and professional socio-economic groups, and respondents residing in owner-occupied accommodation, are both associated with improved odds of broadband adoption. The results indicate that geographic location has a strong effect on the odds of broadband adoption. Specifically, higher population density locations – urban areas and Dublin - are associated with improved odds of adoption. However, I find that geographic location only very weakly influences the odds of a respondent having an Internet subscription of any kind, and I find that the geographic location variables only very marginally improve the predictive power of the general Internet adoption model. It appears rural respondents do not have a relative lack of preference for Internet services, or indeed a relative lack of awareness of Internet services. I conclude from the model estimates that a relative lack of broadband availability in rural areas in particular, but also in non-Dublin urban areas, was the main driving force underlying urban and rural differences in broadband adoption in 2006.

Ireland’s telecommunications market indicators have consistently lagged the rest of Western Europe. Once a country falls behind it then has to outperform just to catch-up and weak pre-existing telecommunications infrastructure can impede the diffusion of later communication technologies in a repetitive path-dependent cycle of underdevelopment. I find some evidence that broadband penetration is influenced by the personal characteristics of consumers. Capacity to pay appears to matter. Specifically, householder characteristics signifying wealth are associated with greatly improved odds of adoption. However, Ireland has a higher level of income per capita than the OECD and it is therefore unlikely that capacity to pay is a disproportionately larger impediment to broadband penetration in Ireland than it is in the OECD. There is also some evidence that third level education is associated with higher rates of adoption, but again, Ireland tends to score above the OECD average in terms of educational attainment. While I fail to find evidence that Irish consumers are less inclined to purchase telecommunications services, this finding does not imply that demand side issues are irrelevant to the Irish experience. The issue is not so much the preferences of Irish consumers, but where those consumers are located, and how many of them there are. Ireland is characterised by a small population, with low population density and high population dispersion. This increases the per capita cost of service provision and makes the Irish market commercially unattractive as a location for investment. The same characteristics were in place during the diffusion processes of the telegraph, the telephone, narrowband Internet and broadband Internet, and they provide a common thread explaining Irish telecommunications market underdevelopment over time. These characteristics will remain impediments to future investment in telecommunications infrastructure suggesting future prospects for the diffusion of next generation broadband in Ireland may follow the historical trend of underdevelopment by OECD standards. Ireland is already trailing the OECD in terms of next generation broadband.

1.4 Conclusion

What would an optimal regulatory and broader policy environment for broadband look like? An important consideration is the tension between short-run efficiency and long-run efficiency. Tight regulatory controls can be problematic. Forcing Eircom to unbundle its local loops for the use of competitors might successfully increase the level of competition in the short-run, but would also reduce Eircom’s incentive to invest in upgrading its network, thereby potentially reducing overall investment in the long-run. The development of the cable network infrastructure, coupled with potential improvements in wireless technology, means that the telecommunications market in Ireland will likely move away from being a natural monopoly in the future and will instead move increasingly toward a more competitive structure based on inter-platform competition. This should help alleviate monopoly concerns in the future. Regulatory support for intra-platform competition may therefore become less important in the future.

What might be appropriate broadband policy for urban locations; may well be inappropriate as policy for rural locations, and vice versa. Market failure is less likely in high population density areas (Faulhaber and Hogendorn, 2001) and policy intervention in these locations should be limited. On the other hand, further state support such as a targeted and conditional subsidy program may be necessary to ensure the delivery of next generation broadband in low density rural areas. The main obstacle to delivering broadband to low density areas is the high capital costs of building out a new system (Weiser, 2008). In contrast the marginal cost of service provision is low. This suggests that any subsidies should be directly linked to the roll-out of infrastructure within the designated target areas. Finally, with rapidly changing technology it may be unwise to enforce hard and fast rules aimed at producing an optimal broadband market structure, or indeed try to enforce an optimal set of underlying institutional structures. Instead it may be more prudent to focus on developing institutional structures with sufficient flexibility to adapt in line with changing technological and market contexts.

Chapter Two: Broadband, Economic Growth and the Wealth of Nations

2.1 Introduction

The overall focus of the research is on the diffusion of broadband Internet. In this chapter I motivate and justify this particular empirical focus. In conjunction with chapter three, the main objective of this chapter is to motivate the subsequent empirical focus on broadband diffusion outcomes in the particular case of Ireland. The first objective of the chapter is to explain why knowledge production and diffusion are central in modern theories of economic growth. The second objective of the chapter is to provide a theoretical underpinning for why technology diffusion happens at the rate that it does in different contexts and environments. The third objective of the chapter is to explain why broadband access technologies are of particular significance for knowledge production and diffusion and therefore for long-run economic growth. Chapter two therefore seeks to make the case for broadband Internet diffusion as a concern of policymakers.

This chapter deals with three linked questions. I start by considering where long-term economic growth comes from and argue that long-term economic change principally derives from the generation, application and diffusion of useful knowledge. The second question concerns the origins and subsequent diffusion of useful knowledge and to help answer the question I discuss underlying themes within modern theories of economic growth and technology diffusion. The third and final question concerns the significance of broadband for the future generation and diffusion of useful knowledge, and also broadband's relevance as a tool of technology policy.

One of my main arguments is that economic production depends on useful knowledge and that the application of new ideas in economically useful ways is the only sustainable source of long-term economic growth. A substantial body of empirical and theoretical work (Kydland and Prescott, 1982; Aghion and Howitt, 1998; Mokyr, 2002) now attributes long-run fluctuations in economic output to technological change. As Aidan Kane (1999, pp. 116) puts it: "For academic economists, the question...what are the sources of technological progress...appears now to be almost co-extensive with the central question of economic science: what determines the wealth of nations". I draw upon the rich traditions of research on economic growth, economic history and the economics of innovation to make the argument that the production, application and diffusion of useful knowledge is the engine transforming the structures and functioning of the economy and society in the long-run. In many respects the stories of economic growth and human history are the stories of technological change, and the stories of changing beliefs and ideas. New knowledge applied in new ways and in new contexts is the critical input enabling sustainable long-term improvements in living standards. According to the standard framework of mainstream economics there are two types of economic growth: extensive growth and intensive growth. Extensive growth is obtained by adding more units of labour or capital, or both, whereas intensive growth is obtained by increasing the average productivity of labour or capital, or both. Extensive growth is constrained in the long-term because labour and capital are subject to diminishing returns. Sustainable increases in per capita output can only be achieved in the long-run through intensive growth. So where does intensive growth come from? Intensive growth comes from combining and applying ideas and technologies in innovative and useful ways that increase the productivity of capital and labour. The economy’s institutional structures, or ‘rules of the game’, are key to the process of knowledge generation and technological change. This is because the rules of the game condition the incentives, expectations, and behaviour of economic actors. Social and economic progress can only be indefinately maintained by developing, nurturing and safeguarding the conditions in which the promethean fire of human creativity can thrive and be rewarded.

That the challenge of improving the material wellbeing of humanity, was in fact the challenge of “utilising natural phenomena and regularities to extract from nature something she does not willingly give us” (Mokyr, 2009, p.12), was a cornerstone of enlightenment thinking. Francis Bacon’s “knowledge is power” dictum (1597) exemplified much of the spirit of the enlightenment age. Development was seen as synonomous with the wrenching free of nature’s secrets, and then using those secrets to transform nature to better suit human needs. Joel Mokyr (1992) describes technological change in similar terms as “the lever of riches”. According to this view, our tools for transforming nature are information, words and instructions. Through technological change we can circumvent the “no free lunch” maxim in economics (see for example, Mankiw, 2008) which maintains it is impossible to get something for nothing. Knowledge once obtained is virtually costless and by increasing our productivity through the application of useful knowledge we can produce the same value of goods and services for increasingly less effort. It is through increased productivity that modern economies have averted Malthusian (1798) crisis and decline as populations have grown. Technological progress and the application of knowledge are ultimately what determine the wealth of nations.

The production and diffusion of knowledge is a complex, interactive and often unpredictable process. For a number of reasons Internet access can play a crucial role in accelerating both knowledge production and knowledge diffusion. The Internet reduces the cost of access to the publicly available stock of knowledge. Internet access also provides low cost and easy to use mechanisms for transmitting information and novel ideas, while also providing a rich environment for the dynamic and often complex interactions involved in the process of consideration, testing and learning. In this way Internet access contributes to the iterative refinement, improvement, expansion and application of useful ideas. Internet access of broadband speed and quality further reduces the costs of finding and using knowledge and provides completely new communication channels through which knowledge flows can be transmitted and received, for example Web 2.0. Joel Mokyr argues:

> What made the West successful was neither capitalism, nor science, nor an historical accident such as a favourable geography. Instead, political and mental diversity combined to create an everchanging panorama of technologically creative societies (Mokyr, 1992, p 302).

Broadband provides access to the diverse panorama of global thought and exposes people to new concepts and ideas. In so doing broadband should increase the rate of ‘mutation’ in the economy. In other words, broadband provides the means to shift the growth rate of innovation to a permanently higher level by reducing the costs of producing and acquiring useful knowledge. If this argument is correct, then improvements in broadband quality and increases in broadband diffusion should support a higher rate of economic growth over the long-term.

The empirical literature broadly supports the hypothesis that there is a relationship between broadband diffusion and growth. In this context there may be a case for governments’ to establish a political, social and economic environment conducive to the successful diffusion of broadband. Caution is required when diagnosing success or failure in a particular market as technology diffusion is a dynamic, complex and unpredictable process. Nevertheless, the wide variation in broadband diffusion across advanced economies is an empirical fact. Ireland consistently ranks below the OECD average for a range of broadband indicators including availability, usage, price, speed and penetration. Irish Government policy, as expressed in official documents, has repeatedly emphasised the importance of innovation for economic growth. By 2010 Ireland was intended to be: “internationally renowned for the excellence of its research and be at the forefront in generating and using new knowledge for economic and social progress, within an innovation driven culture” (IDCSTI, 2004). The

Government has consistently maintained official commitment to the knowledge economy even in the midst of the post 2008 economic crisis; see for example DCENR (2009). In a similar vein, the key role of broadband Internet access as an essential platform for the knowledge economy has been regularly highlighted by government bodies (Forfás, 2010 and 2011). Despite official policy towards broadband Ireland's broadband market development has lagged behind most of the rest of Western Europe. The importance of broadband for long-run growth and the apparent failure of the broadband market in Ireland provide the justification and motivation for the empirical work on broadband diffusion in Ireland that follows in subsequent chapters.

2.2 The Engine of Economic Growth

There are a number of seminal overviews of the main theories purporting to explain the causes of economic growth (see for example Bart Verspagen, 2005; David Warsh, 2006; Daron Acemoglu, 2009; and Philippe Aghion and Peter Howitt, 2009). The most influential of the contemporary growth theories include the new growth theories; the evolutionary growth theories; the neo Schumpeterian growth theories, as well as the various growth theories rooted in complex models of the economy. The position of technological change and innovation as the primary engine of long-term economic growth was recognised by a number of economists in the early twentieth century, including by Allyn Young (1928) and by Joseph Schumpeter (1942). However technological progress was only accorded secondary status by the orthodox growth models of the early twentieth century. Growth in the capital stock and growth in the size of the labour force were considered to be the main causes of growth. Higher levels of investment were seen as leading to faster capital accumulation and factor accumulation was in turn seen as the cause of increases in per capita output. William Easterly and Ross Levine (2001, p.2) note that the emphasis on factor accumulation has persisted in the economic growth literature, for example they point to Debraj Ray (1998) as referring to investment and savings as "the foundations of all models of economic growth".

Economic research began to increasingly focus on technological change and innovation from the 1950s onwards. The neoclassical growth models of Robert Solow (1956, 1957) and Trevor Swan (1957) explained how the per capita level of output produced in the economy would be static in the long run unless the productivity of capital and/or labour grew over time. Diminishing returns to capital and labour would make it impossible to sustain economic growth in the absence of such productivity improvements. Per capita output was seen as having a long-run constraint which depended on the savings rate. As the capital stock increased so too would the total capital depreciation in each time period. Eventually the annual capital stock depreciation would become so large it would completely cancel out the annual additions to the capital stock at a given savings rate. Sustained long-term growth could only be achieved in the Solow-Swan models if there was technological progress. Moses Abramovitz (1956) and Solow (1957) used growth accounting methods to separately estimate that fully 85 to 90 per cent of economic growth in the US economy over the previous century could not be explained by the increases in the capital stock and the labour force over that period. Attention focussed on the source of the unexplained or 'residual' growth. Solow (1956, 1957) and Swan (1957) both assumed the residual growth was explained by higher productivity caused by technological progress. They posed the question of how and why this technological progress came about, and although the Solow-Swan growth models incorporated the effects of technological change within the unexplained residual, the models also assumed technological change was exogenous to the economic system. The unexplained residual within these models is now commonly called Total Factor Productivity (TFP). TFP represents growth in the productivity of capital and labour, though as Easterly and Levine (2001) point out, TFP includes not just changes in technology but also factors such as changing policies and institutions. Indeed Abramovitz (1956) argued the residual included a number of elements besides technological progress. He described the residual as a measure of our ignorance about how the economy changes over time. One shortcoming of the basic Solow-Swan neoclassical growth model was that the long-run per capita growth rate was entirely determined by an element outside or 'exogenous' to the model (Snowdon and Vane, 2005). While the basic neoclassical growth models did not explicitly seek to explain the causes of technological change, they are nevertheless important because they highlight the crucial role of technological change in determining long-run standards of living.

Nicholas Kaldor (1957) made technological change endogenous by introducing a 'technical progress function' to his growth model. The Kaldor model emphasised the role of endogenous positive feedback loops between economic growth and knowledge generation. Kenneth Arrow (1962) developed an endogenous 'learning by doing' growth model, in which serendipitous learning generates technological progress as a by-product of economic activity. Arrow showed how the productivity of labour would increase with experience while technological progress caused by learning raised the marginal productivity of capital. These productivity increases could counteract the effect of diminishing marginal returns to capital and labour. The learning by doing model was similar to the older exogenous neoclassical models with the exception that it did not assume diminishing returns to factor inputs. Arrow (1962, 1991) argues that, while the cost of acquiring knowledge is independent of the scale on which the knowledge is eventually used, the benefit obtained from the knowledge very much depends on the scale at which it is eventually used. However, although knowledge has a once off payment, this payment is of unknown cost beforehand, and this makes its production inherently risky. Once the knowledge is created there is almost zero marginal cost involved with further use of the knowledge and knowledge once created is virtually inexhaustible. Arrow contends it is the inexhaustibility of knowledge which is the source of the increasing returns to scale necessary to generate long-term increases in productivity. Knowledge is also ‘non-rivalrous’ meaning one person’s use does not reduce another person’s use. This particular characteristic of knowledge generates positive externalities in the economy. However, knowledge is only partially excludable and this means that the producer of the knowledge will often be unable to obtain all of the benefits from its production. The inherent uncertainty in the cost of producing knowledge, combined with the inability of the producer to internalise all of the benefits of its production, implies there will be underproduction of knowledge by the market in the absence of policy intervention. The early endogenous models represent important advances in understanding economic change because they were the first mainstream growth theories to offer explanations for why technological change occurred and for why it propelled economic growth.

According to Paul Romer (1992 and 1993), technological change offers the possibility of continuous growth in living standards. Romer emphasises the vast number of ways in which any economic activity can be conducted. He describes each known combination of actions as a known technology, and each possible combination of actions as a potential innovation. Romer gives the example of sewing a shirt, an activity which requires fifty two separate actions. Romer argues that even if most possible sequences of action are wildly impractical it is still “extremely unlikely that any actual sequence that humans have used for sewing a shirt is the best possible one” Romer, (1992, p. 69). His argument is that the potential for continuous economic growth exists within the vast search space of untried combinations of actions. Morton Kamien and Nancy Schwartz (1982) argue that technical change may be the single most important determinant of our past, present and future, while Robert Barro and Xavier Sala-i-Martin (1997) have developed a model that generates a form of conditional convergence of incomes between countries based on the diffusion of technology across countries and Stephen Parente and Edward Prescott (1994) find technological differences explain international differences in per capita incomes. What factors are likely to influence the technological differences that influence economic development?

2.3 Theories of Economic Growth

New growth theories

Modern neoclassical growth theories emphasise the importance of investment in technological change, human capital and innovation. These new growth models, assume technological change occurs endogenously within the economic system (Barro and Sala-i-Martin, 2003, pp. 205-285) and that positive externalities from new ideas and innovation impacts on long-run economic growth and development. New ideas and technical change are seen as determined, or induced, by the purposive motivations and decisions of economic actors, and they are therefore considered ‘endogenous’ to economic activity. The core methodological underpinnings of neoclassical economics are perfect rationality, consistent preferences and general equilibrium. The new growth models emerged in the 1980s and their central proposition is that capital accumulation when taken in its broadest sense to include human capital does not exhibit diminishing returns (Mankiw, Romer and Weil, 1992). The growth process is seen as driven by the accumulation of human and physical capital together with the production of new knowledge created through R&D (Snowdon and Vane, 2005).

Robert Lucas (1988) replaced Solow’s exogenous growth model with a model incorporating the spillover of ideas. Spillover happens when individuals become exposed to new ideas and in the Lucas model this exposure occurs through proximity to other people. Romer (1986, 1987 and 1990) built on Arrow’s (1962) learning by doing model by introducing an R&D sector. Romer was able to show how increasing returns to scale could be achieved at the aggregate level through the spillover of technology. The non-rivalrous characteristic of knowledge enables new ideas to be used over and over again at no additional cost to the firm once created (Romer, 1990) and according to Romer’s (1986) endogenous growth model learning externalities among firms caused by knowledge spillover leads to an expansion of aggregate knowledge. As the benefits of a firm’s investment in knowledge cannot be fully internalised, the investment in knowledge (R&D) by one firm generates a positive externality that increases the productivity potential of other firms and economic actors. Romer’s (1987) product variation model describes a process in which innovation improves the productivity of labour and capital through specialisation and the creation of new types of products. The model does not require new products to be improvements on older products because increased specialisation and product variety itself raises the economy’s productive potential. The increased product variety enables the existing stock of labour and capital to be spread over an increasingly large number of uses. As each type of productive activity exhibits its own particular diminishing returns, the overall scale of the diminishing returns can be counteracted through the production, by the R&D sector, of new useful knowledge which increases the number of ways in which the stock of capital can be used. In the new-growth models the public benefits to R&D exceed the private benefits. Knowledge producing firms are often unable to appropriate all the benefits from their knowledge production (Romer, 1990), therefore when left to its own devices, the market will produce less than the socially optimal amount of new knowledge. The resulting market failure is the standard rationale advanced in favour of activist technology policy, whether in the form of R&D subsidies or tax breaks for the private sector, or in the form of direct government investment in R&D. Bart Verspagen (2005) has criticised the new growth theories for their emphasis on rational decision makers. He argues the new growth theories sacrifice a large amount of realism in return for a quantitative modelling approach that provides strong analytical consistency.

Evolutionary theories of economic growth

The neoclassical underpinnings of the new growth theories contrast with the evolutionary nature of economic change emphasised by Nelson and Winter (1982); by Paul David (1990), and by Mokyr (1992). These evolutionary, or path dependent, theories of economic change reject the assumption of rationally optimising individuals. In addition, economic systems are considered to be dynamic and permanently out of equilibrium. While the new growth models treat technological change as endogenously induced, the evolutionary approach argues that economic change occurs as part of a historically grounded path-dependent process. The path dependent nature of technological change is emphasised by Nelson and Winter (1990). According to this view, new ideas, like mutations, are not entirely random. All ideas emerge out of something else, and are almost always variants on ideas that already exist. Bart Verspagen (2005) contrasts the steady-state or ‘clockwork’ growth pattern of the new growth theories with the more uncertain growth trajectories predicted by the evolutionary growth theories. Innovation is seen as ‘blind ‘ (Metcalfe and Georgiou, 1997, p.9), and driven by economic processes.

The evolutionary framework stresses that dynamic change happens over historical time with the rate and type of technological change occurring as part of a stochastic process. Kurt Dopfer (2005) argues that no single organisation or individual can perfectly foresee the path of economic change or the potential of a new innovation. Rather than possessing perfect rationality under all circumstances, organisations and individuals are deemed to act under conditions of bounded rationality. Bounded rationality assumes economic actors are only partially rational and experience cognitive limitations and biases in their ability to formulate; process and solve complex problems (Kahneman, 2003 and 2011). Thus individuals and organisations must learn and search experimentally in uncertain and permanently changing environments and with uncertain outcomes (Hanusch and Pyka, 2005). Uncertainty of outcome is a function of what Mokyr (1992) describes as the Darwinian nature of technological change. According to this view, markets are treated as selecting, or adopting, new innovations or ‘novelties’ within a constrained Darwinian process. Innovations occur stochastically within the economic system, with the eventual success or failure of a particular innovation unknown in advance. The novel idea underpinning the innovation can be seen as synonymous with a mutation. The innovation’s eventual success or otherwise will partially depend on luck and context, but will also depend on the innovation’s own characteristics such as its usefulness, its applicability, its compatibility with existing technology and its relevance to perceived needs. These evolutionary path-dependent theories suggest the appropriate role of government is to create an environment and set of incentives that encourages the testing of ideas and the production and diffusion of innovation.

Complexity theories of economic growth

While the evolutionary framework may provide a more realistic description of the ‘black box’ of technological change Vernon Ruttan (1997) argued that it had so far failed to become a productive source of empirical output. The evolutionary approach has since been supplemented by a number of insights from the field of complexity theory. The various complexity models of economic growth consider the economy to be a complex adaptive system characterised by a multiplicity of interactions between economic actors and by a multiplicity of positive and negative feedback loops (Simon, 1969; Frenken, 2005 and 2006; Arthur, 2009). The complexity models describe economic change occuring through the exploitation of increasing returns. These increasing returns derive from new and useful innovations. Innovation is itself seen as an ongoing iterative process characterised by positive feedback loops. Economic actions are seen as mediated by institutions i.e. by the legal, political and cultural rules of the economic system, rather than by a central controller (Arthur, 1994; Arthur, Durlaf and Lane, 1997). These institutions are seen as critical in determining the rate of production and diffusion of innovation.

Koen Frenken (2006) describes a new cohort of models of technological change which focus on innovation as a complex phenomenon and which use modelling techniques from complexity science such as fitness landscape models, percolation models, and complex network models (Cowan, 2004). These models illustrate the extreme difficulty involved in predicting the outcome of any action taken, or policy decision made, within an economic system. The reason is that the action or policy impacts upon a complex system of interrelated and often unknown factors. A complex system, such the economy, will be characterised by non-linear relationships and by emergent properties, and will therefore be inherently unpredictable. Optimal outcomes cannot be guaranteed (Arthur, 2009). New possibilities are seen as continuously emerging within the system as part of a dynamic process and consequently the economic system can never fall into equilibrium. Indeed the attainment of equilibrium is analogous to the death of economic change and the end of improving living standards. What does such a view of the economy and of economic change imply for policy? Such a view underlines the difficulty in picking winners and provides a rationale for a non-interventionist technology policy. Instead of picking winners, policymakers should seek to facilitate; nurture and safeguard a diverse, creative, dynamic and genuinely competitive marketplace of ideas with its own internal processes of Darwinian selection. Culture and institutions are important because they influence the spread and adoption of ideas. The prevailing environment, including the prevailing beliefs, types of knowledge flows, sets of incentives, and rules of the game, will determine the long-run rate of production and diffusion of innovation and will therefore determine the long-run rate of economic change.

Neo Schumpeterian growth theories

The neo Schumpeterian theories of economic growth (Segerstrom, Anant and Dinopoulos, 1990; Grossman and Helpman, 1991; and Aghion and Howitt, 1992) retain many elements of the neoclassical framework yet combines the evolutionary perspective of technological change as a path-dependent process with an understanding of the economy as a complex system. According to the neo Schumpeterian framework the transformative processes driving economic change are endogenous to the economic system and a function of knowledge production, innovation and entrepreneurship occurring at the micro level (Hanusch and Pyka, 2005). Innovations will often be combinations of two or more existing ideas and can manifest as new products or services, new processes, new markets, new sources of supply or even new organisations. Philippe Aghion and Peter Howitt (2009) identify two main inputs to innovation: (a) expenditures made by the public and private sectors to produce innovations, and (b) the publicly available stock of innovations already produced by past innovators. Technological change is seen as induced by the deliberate actions of economic actors responding to economic incentives. One of the key contributions from Joseph Schumpeter’s seminal 1942 work *Capitalism, Socialism and Democracy* was the idea that competition between innovations, rather than competition between firms, is the central force propelling economic growth. Schumpeter saw technological competition, or competition between innovations and ideas, as the key to improving living standards. Modern neo Schumpeterian analysis argues that economic growth occurs through the introduction of new and quality-improving innovations to the economy. These innovations cause the aggregate level of productivity in the economy to increase. The economy will enter a new phase of growth as newer and more efficient technologies spread throughout the economy. The new technologies render the older products and services obsolete and raise the economy’s productive potential. Jobs, businesses, and even industries, which are unable or unwilling to adapt to the new reality will eventually be replaced by those better able to exploit the newer more efficient and useful technologies. This process of economic upheaval and change is seen as perpetual. Economic change ebbs and flows along with what Schumpeter calls the ‘creative gales of destruction’. Schumpeter states: “Economic progress, in capitalist society, means turmoil” (Schumpeter, 1942, p. 32). Over time the newer innovations are themselves displaced by the next wave of innovations and the productivity potential of the economy increases yet again as the economy fluctuates and remakes itself in turmoil. Economic growth is seen as sustainable ad infinitum provided the process of creative and destructive innovation is allowed to continue indefinitely (Aghion and Howitt, 2009).

The neo Schumpeterian growth models argue that certain transformative technologies generate periods of radical economic change and that these periods of change are punctuated by more extended periods of smoother economic development and incremental change (Hanusch and Pyka, 2005). The idea of transformative technologies is similar to Mokyr’s (2002) concept of macroinventions and Bresnahan and Trajtenburg’s (1995) concept of General Purpose Technologies (GPTs). Macroinventions are the big ideas that feed off each other and counteract the propensity for cumulative small inventions to run into diminishing returns. Macroinventions can be seen as propelling anew a stagnating economy approaching or at a technological ceiling. Similarly, Timothy Bresnahan and Manuel Trajtenberg (1995) and Elhanan Helpman and Trajtenberg (1998) use the concept of General Purpose Technologies (GPTs) to explain the periodic occurrence of these leaps and bounds of innovation. GPTs are innovations with the ability to easily recombine with other techniques, that are pervasive in the economy, and that have numerous economic applications. The introduction and subsequent development of a GPT opens up a wave of new possibilities for innovation and propels the economy forward.

Transformative technologies

Joel Mokyr (1992 and 1993) describes the concept of transformative technologies. Mokyr distinguishes between microinventions, representing iterative improvements in existing technologies, and macroinventions which represent major technological breakthroughs. Macroinventions are inventions in which “a radical new idea, without clear precedent, emerges more or less ab nihilo” (Mokyr 1992, p. 13), and he argues “without such breakthroughs technological progress would eventually fizzle out” (Mokyr, 1992, p. 14). Internet access technologies do not appear to exhibit the characteristics of a Mokyrian macroivention. The invention of the microprocessor; the invention of packet switching, and the development of the ARPANET (the Internet’s predecessor), are all much more plausibly described as macroinventions. The development of Internet access technologies during the 1990s might better be described as the point at which these innovations and other related technological developments advanced sufficiently to collectively produce a technology of pervasive utility throughout the economy.

On the other hand, information technology in general, and Internet access technologies in particular, have been regularly identified as prototypic General Purpose Technologies (see for example Jovanovic and Rousseau, 2005; Ruttan, 2008; and Van Ark, Gupta and Erumbam, 2011). What are General Purpose Technologies (GPTs) and why are they important for economic growth? The concept of GPTs has been developed by David (1990), Bresnahan and Trajtenberg (1995), Elhanan Helpman (1998), and Carlaw and Lipsey (2006). GPTs are described as technologies possessing at least three particular characteristics: (a) high potential for improvement, (b) pervasiveness in the economy, and (c) innovation enhancing. Potential for improvement simply means the technology has inherent potential for technical improvements, while pervasiveness means the technology is almost ubiquitous within the economy. The implication of technological pervasiveness is that improvements in the technology will lead to productivity gains in multiple sectors of the economy. Finally, innovation enhancing means the technology enhances the productivity of R&D elsewhere in the economy. Timothy Bresnahan and Manuel Trajtenberg (1995) suggest a limited number of transformative technologies have accounted for a disproprtionately large amount of the historical growth in productivity. Steam power, the telegraph, the railroad and the electric motor can all be seen as having lowered transportation and/or communication costs. These technologies all had the effect of increasing the density of interpersonal and company networks in the economic system because they joined together smaller regional markets into larger markets. Internet access technologies can be seen as creating a single global market for certain goods and services, and in particular for information-based goods and services. In addition, due to their pervasiveness, GPTs open up more technological possibilities than more specific or niche technologies. The more generally applicable the technology is within the economy, the greater the technology's potential for driving economic growth. As the quality and usability of the GPT improves over time its pervasiveness in the economy means that these improvements lead to generalized economy wide productivity gains. The expectation is that innovations related to a GPT will generate higher returns for the economy in the long-run than will innovations associated with more conventional goods. Vernon Ruttan (2008) argues the periodic development of new GPTs is necessary to sustain economic growth over the long-term. According to Ruttan the maturing of normal evolutionary technologies eventually results in the dampening of productivity growth because iterative improvements in the existing technological base become rarer and more costly over time.

Economic growth theories emphasising the importance of transformative GPTs show how periods of innovation will often occur in clusters. This prediction is in contrast to the steady-state rate of innovation described by the new growth models. In the short and medium term GPTs act on economic growth through innovative complementarities and positive feedback loops. However, in the long-run the high growth rate expansion is constrained and time specific because new innovations become rarer and more costly to develop as the GPT and its related innovations gradually mature over time. The Schumpeterian clusters of innovation can be explained by the idea of combinatorial innovation (Romer, 1992 and 1993; and Varian, 2004). Combinatorial innovation occurs when a set of components are combined and recombined to create numerous new innovations. Hal Varian identifies the introduction of certain ICT components and the subsequent Internet boom of the 1990s as an instance of this phenomenon occurring. In this instance, the digitization of information combined with access to the Internet represented a form of GPT. The Internet transformed the connectivity of individuals and organisations and in so doing transformed the density of the economic system. The new and more densely connected system had an enhanced capacity to absorb and exploit new ideas. Novel pieces of software could be sent around the world in seconds to be combined and recombined over and over again with other software components to create new products and services.

Market failure and GPTs

Inherent characteristics of knowledge goods such as uncertainty in production, and non-rivalrousness, will often lead to market failure in the production of knowledge (Arrow, 1962 and 1991; Goel, 1999). Although the characteristics of knowledge generate productivity gains and increasing returns to scale at the level of the economy, they also make it difficult for the producers of the good to appropriate all of the benefits of knowledge production. Charles Jones and John Williams (1998 and 2000) estimated that the social (i.e. economy wide) rate of return to R&D is between two and four times the private rate of return to R&D. The inability of knowledge producers to internalise all of the benefits of their investments in R&D reduces their incentive to undertake such activity and leads to a socially suboptimal level of knowledge production. In addition, the production of new knowledge is inherently uncertain and this differentiates its production from that of more conventional goods. There can be no guarantee that useful knowledge will be produced at the rate hoped for by the knowledge producer. The uncertainty of production further diminishes the incentive to invest in R&D and reduces the overall level of knowledge produced. Vernon Ruttan (2008) argues that GPTs encourage greater investment in R&D because they increase the productivity of R&D investments. Thus GPTs, such as the Internet, can reduce the degree of market failure in the production of knowledge. This argument provides a rationale for public intervention to support the development and diffusion of Internet access technologies. Robert Atkinson (2007a and 2007b) has advocated an interventionist broadband policy in the United States citing positive externalities associated with broadband access, such as generalized economy wide effects on productivity and growth. However, Robert Crandall (2010) disputes the value of such government interventions in telecommunications markets. He argues there is no evidence universal service programs increased telephone penetration in the United States despite $5 billion per year in government subsidies.

The ultimate impact of technology

The origin of technological change is an issue of fundamental importance for human wellbeing. W. Brian Arthur puts it this way:

> ...at the very core of where technology is generated, at the very core of the process that over decades generates the structure of the economy and the basis of our wellbeing, lies a mystery. From what process then...from what source...do the devices and methods and products that form the economy originate (Arthur, 2009, p. 108)?

However, no matter how useful the technology is, the technology’s impact will ultimately depend on its diffusion and pervasiveness within the economy and society. Useful ideas have historically spread through observation and communication. A wide variety of historical trends have facilitated the diffusion of knowledge and it may be unwise to rely on a single methodological framework to fully understand and explain the phenomenon of technology diffusion. So how can we explain differences in the diffusion of technology and new ideas? Economic theory provides us with a number of different insights.

2.4 The Diffusion of Knowledge and Innovations

Bronwyn Hall (2005) describes technology diffusion as the process by which individuals and firms in an economy and society adopt novel technologies or replace older technologies with improved versions. She describes the diffusion process as an intrinsic part of the innovation process. Learning in different contexts, as well as imitation and feedback effects, will enhance the original innovation and then spawn new innovations. An innovation may spread through the economy when it is clearly superior to previous technologies via a ‘learning by observing’ process in the Darwinian sense described by Nelson and Winter (1982) and by Mokyr (1992). However, as Nathan Rosenberg (1972) points out, the diffusion process can take a long time and is not guaranteed to succeed. There has been a wide variation in the rates and speed of acceptance of even successful innovations. While the rates and speed of adoption of different technologies exhibit wide variation, Zvi Griliches (1957) and Edwin Mansfield (1963) find that successful technologies tend to exhibit a path dependent S-shaped diffusion curve over time. The S-shaped diffusion curve has been subsequently identified in a multitude of empirical studies. What causes the variation in the diffusion processes of different technologies? It may be that the diffusion process is influenced by certain characteristics of potential technology adopters, for example their income levels and their levels of educational attainment. The wider economic environment is also likely to influence the diffusion process. In one of the first empirical studies of technology diffusion, Griliches (1957) found that the diffusion of seed corn depended on economic factors such as expected profits and the size of the adopter’s businesses. However he also found the diffusion of the seed corn depended on the activities of the suppliers of the technology. The strength and nature of social networks also appear to influence the diffusion process (Rogers, 1995). Austan Goolsbee and Peter Klenow (2002) in a study of home computer adoption, found the influence of friends and neighbours had a significant positive effect on adoption decisions. The effect was present even after controlling for income, price and demographic effects.

Everett Rogers (1995) has identified a number of technology characteristics which, he argues, influence the decisions of potential adopters. Roger's five characteristics are:

1. Relative advantage over other technologies,
2. Compatibility with existing norms and practices,
3. Complexity,
4. Trialability and
5. Observability.

Bronwyn Hall (2005) identifies four categories of factors which she argues influence the diffusion path of innovations. Hall's four categories are:

a. Factors influencing the perceived benefits received from adopting the innovation,
b. Factors influencing the perceived costs of adopting the innovation,
c. Factors related to the industrial and social environment and
d. Factors related to uncertainty and information problems.

Some of these factors may change over time and such changes will influence the diffusion process. For example, the relative advantage of a new product may be quite small to begin with but its benefits may subsequently increase over time as the technology is gradually improved and as more and more applications for the technology are developed. The benefit of the product may also increase as the number of users increases, a phenomenon known as a positive network effect. This effect may be particularly relevant for communication goods where there are likely to be direct network effects. Relative advantage will also improve where the cost of a new technology declines over time. This could happen, for example, if the production process is improved or if larger market size generates economies of scale. The concept of 'Innovation Systems' was developed in the late 1980s and early 1990s to explain why different economies and societies differ in their rate of innovation and in their rate of diffusion of innovation (Freeman, 1991; Lundvall, 1992; Nelson, 1993; Edquist, 2005). The approach emphasises the systemic nature of innovation processes. The level and types of knowledge flows in the economy as well as the nature, density and strength of the relationships between people and organisations are seen as crucial to innovation. One implication is that the rate of innovation is enhanced by having an open society with multiple transparent flows of knowledge and a robust system of institutional and personal networks. The economic system's ability to generate original ideas and communicate and assimilate existing innovations is referred to by Stern, Porter and Furman (2002) as its ‘Innovative Capacity’.

Factors influencing the historical diffusion of innovation

The historical diffusion of innovations has been heavily influenced by the development of communication and transportation technologies. Improvements in communication technologies increase the connectivity of individuals and organisations and thereby increase the density of the economic system. This facilitates the transmission of useful ideas and the diffusion of innovations. The genetic mutations which enabled polysyllabic speech are estimated to have first occurred around two hundred thousand years and it was probably this development that first allowed humans to efficiently communicate complicated concepts and ideas (Botha and Knight, 2009). According to Mokyr (1992) the spread of new ideas, and indeed the preservation of old ideas, was subsequently aided by the development of a series of information and communication technologies. Improvements in communication technologies transformed the codification, transmission and diffusion of new knowledge and increased the durability of existing knowledge Notable pre-modern technological advances of this type include the development of symbols thirty thousand years ago, the development of writing seven thousand years ago, and the development of Gutenburg’s printing press in the middle of the fifteenth century (Foray, 2004). Long-distance communication was transformed in the nineteenth century, first by Morse’s invention of the telegraph in 1845, and then subsequently by the invention of the telephone by Bell and Gray in 1876. Advances in transport technologies in the eighteenth and the nineteenth century also helped accelerate the diffusion of knowledge. Important advances included the invention of the steam engine and the steam boat in the eighteenth century and the expansion of the railroad following Bessemer’s invention of the blast process in the mid-1850s (Bernstein, 2008). Kevin O’Rourke and Jeffrey Williamson (2001) describe how the advances in communication and transport technologies facilitated the trend towards globalisation in the nineteenth century, the commensurate shrinking of the world, and the increased awareness of the ideas of other cultures. Advances in communication technology continued in the twentieth century. Bart Van Ark, Abhay Gupta and Abdul Erumban (2011) argue the development of the microprocessor in the 1950s has had a greater transformative effect on the economy than the development of any other information and communication technology in the past. While this position is undoubtedly controversial, the invention of the microprocessor certainly initiated the development of a series of incremental innovations which in time was to lead to the development of both mainframe computers and to the Internet.

Increasing proximity to other people has also influenced the historical diffusion of innovation. Michael Kremer (1993) contends that the rate of innovation is related to population size. He argues that each person has a non-zero chance of adding to the stock of knowledge as well as a non-zero chance of applying pre-existing knowledge in a novel context for economic gain. If Kremer's argument is correct then larger populations imply a higher rate of innovation. The heterogeneous characteristics of diverse economic actors can itself be seen as a potential source of innovation. In this view, diverse and cosmopolitan societies are more likely than closed and parochial societies to produce their own innovations and to embrace external ideas. In his overview of human history, the anthropologist Jared Diamond (1997) shows how regions with the highest population densities have consistently produced new technologies at exponentially faster rates than regions with lower population density. Lucas's spillover concept is useful as an explanation for this phenomenon. Greater proximity to other people makes you more likely to become aware of other people's ideas and knowledge and thus more likely to subsequently combine those ideas with other ideas as a new innovation. Bettencourt, Lobo, Helbing, Kuhnert and West (2007) have found there is superlinear scaling of innovation in urban environments. Measures that scale superlinearly increase consistently at a nonlinear rate greater than one-for-one. Thus a city ten times larger than its neighbour will be more than ten times more innovative. In other words, because of superlinear scaling, the per capita level of innovation is higher in locations with large populations and large population densities such as cities. Smaller populations also make specialisation more difficult. The significance of specialisation was one of Adam Smith's key insights in *The Wealth of Nations* (1776). Smith argued that specialisation would lead to greater skill and greater productivity on particular subtasks. The wide-scale availability of Internet access can be seen as increasing the 'effective population' which people have proximity to, albeit a virtual proximity as opposed to physical proximity. In this sense, the Web functions like a virtual city (Johnson, 2010). Access to the Web connects previously semi-isolated local and regional economies into a more closely integrated global economy. For each regional economy the stock of knowledge from which innovations can be produced is expanded, thereby increasing the number of feasible innovation possibilities.

The historical diffusion of innovation has also been heavily influenced by changing institutions. Every society operates under its own set of legal and cultural 'rules of the game'. Douglass North terms these rules of the game as 'institutions' (North, 1990 and

2005). North emphasises the importance for technological change of the nature of the constraints structuring political, economic and social interactions. These constraints are the laws, regulations, and norms which impact upon the incentives and behaviour of individuals and organisations. The enforcement of, and adherence to these rules, are an important element of the institutional architecture, as indeed are the consistency, reliability and respect for these rules. Institutions can be regarded as the structures that humans impose on themselves to order their environment. They can therefore be seen as a form of technology. As North puts it (2005, p.13): "the construction of an institutional framework has been an essential building block of civilization". According to the institutional perspective the rate of innovation depends not just on the market and on market players but also on a variety of other factors including the institutional constraints. Examples of institutions include, but are not limited to, the strength and predictability of property rights, the education system, the workings of the financial system, the regulatory system, the pervasiveness of corruption, the quality of governance, the level of political stability, fiscal policy including the design of the tax system, the legal system including the existence of patent law, as well as social and cultural norms (World Bank, 1997). The prevailing set of institutions influences the costs and benefits of engaging in knowledge production and in other innovative activities. Institutions will influence the rate of innovation in an economy to the extent they alter the incentives of individuals and organisations to innovate. For example, Adam Smith (1776) identified the importance of secure property rights in providing an incentive for individuals to invest and accumulate capital. The strength and predictability of property rights in Britain from the eighteenth and nineteenth century onwards is a plausible, albeit partial, explanation for why the industrial revolution first occurred in Britain as opposed to another European country, and for why it occurred when it did. Inventors and innovators in Britain from the eighteenth century onwards had much greater confidence that they would be able to benefit from their innovative activity. The institutional change had increased the net benefit, and therefore overall level, of innovative activity.

Modelling technology diffusion

Successful instances of technology diffusion tend to exhibit an S-shaped diffusion curve. The S-shaped diffusion curve can be explained by a variety of different models. There are a number of surveys of technology diffusion models, for example, by Massoud Karshenas and Paul Stoneman, (1995); by Paul Geroski, (2000), and by Stoneman (2001). I draw on these surveys in the current section. Geroski (2001) describes a number of models. For example, models of density dependence describe how evolving forces of legitimation and competition help establish new technologies before ultimately constraining their take-up. However, the two most influential diffusion models are the epidemic model and the probit model. According to the epidemic model consumers learn about the new technology at different times and the overall level of adoption is limited by the diffusion of information about the technology. In the simplest version of the epidemic model awareness of the technology is the principal factor determining adoption patterns. It is assumed consumers adopt the technology when they become aware of it. Awareness of the new technology is transmitted like an infection through social networks, or through other channels of communication. The probability of acquiring the infection increases over time as the percentage of the population carrying the infection increases. During the early phase of the diffusion process the rate of new adoptions will increase in each time period. This is because the rate of infection increases in each time period. However, the number of people still to be infected, yet susceptible to the infection, is also declining over time. When a certain threshold is reached, the negative effect exerted by the decline in the number of new potential carriers will exceed the positive effect exerted by the higher probability of a given individual acquiring the infection. When this point is reached the market will reach its saturation point. This process generates the S-shaped diffusion curve.

The main alternative to the epidemic model is the discrete choice or ‘probit’ model. Discrete choice models assume the decision to adopt a technology is a rational choice made by a particular individual, firm or institution. The probit model and the closely related logit model both assume that consumers choose to adopt new technology when their expected net benefit from adopting the technology exceeds the perceived opportunity cost. The adoption choice depends, amongst other things, on the particular characteristics of the individual or organisation including their knowledge, preferences and capabilities. It is assumed the differences between consumers will partially explain technology adoption decisions and that the adoption event will occur when the expected benefit to the consumer from adoption x exceeds a threshold cost y. Suppose consumers differ in some bundle of known and unknown characteristics z and that z positively affects the expected benefit x. We expect that consumers will adopt the technology provided the cumulative effect of z on x exceeds some level y. If the distribution of expected benefits exerted by the bundle of characteristics z is normally distributed in the population, and the threshold cost y declines at a constant (monotonic) rate over time, then we derive a diffusion curve with the stylised S-shape. Alternatively, if the technology is characterised by a direct network effect (see Shy, 2001) then the value of the product will increase as more and more people become users. In this case, if the distribution of expected benefits over consumers is normally distributed in the population, then the S-shaped diffusion curve can be generated as part of a feedback process regardless of whether costs decline over time.

In recent years a number of diffusion models drawing on principles from complexity theory have been developed. For example, in the complex network models, Robin Cowan (2004) shows how network relations between innovating agents affect the rate of diffusion. Diffusion is seen as occurring when information or knowledge passes from one agent to another, while networks are seen as fluctuating, dynamic and evolving over time. Diffusion of tacit knowledge within the network depends heavily on the nature of the network of agents through which it spreads. More dense networks of agents will exhibit higher rates of diffusion, while better connected agents within the network are more likely to become technology adopters. Koen Frenken (2006) shows how percolation models can also explain the technology diffusion process. In the simplest percolation model each individual agent is assumed to have four neighbours. Each agent is assigned a different preference threshold p for the new technology or product and these preferences are uniformly distributed in value between 0 and 1. If an agent is informed about the existence of the product then he or she will evaluate whether the product quality q is greater than his or her preference threshold p. If q is perceived to be greater than p then the agent will adopt the product and will inform his or her four nearest neighbours of the product's existence. It can be shown the maximum rate of adoption for the product is equal to the product quality q. However, the actual rate of adoption is likely to be lower than q because many agents will never find out about the product in the first place. The diffusion process generated by the percolation model can be shown to exhibit regional variation. Widespread diffusion of the technology may occur in certain regions while diffusion may be low in other regions.

Factors influencing ICT diffusion

The particular focus of this work is on the diffusion of communication technologies in Ireland. Of particular interest is the diffusion of broadband Internet. Broadband Internet is of interest because it exhibits the characteristics of a General Purpose Technology (GPT) and because GPTs are associated with the transformation of economies and societies through waves of productivity enhancing innovations. The empirical literature identifies a number of factors as being relevant to the diffusion of Information and Communication Technologies (ICT). For example, Francesco Caselli and Wilbur Coleman (2001) estimate that human capital significantly affects the rate of purchase of new computer systems. They found workers with lower levels of skills required additional training and this represented an additional cost for the firm. The implication is that educational attainment may influence ICT adoption patterns. At the level of the firm, there is evidence firm size may be positively related to ICT adoption (Rose and Joskow, 1990). This may reflect the greater ability of larger firms to absorb the costs of adoption and in some cases may reflect greater economies of scale. The expected significance of cost as a barrier to technology adoption suggests that the income and wealth of individuals, as well as of firms, will influence adoption decisions. Stephen Parente and Edward Prescott (1994) argue that barriers to technology adoption such as regulatory or legal constraints are often intentionally or unintentionally placed in the paths of entrepreneurs and individuals and that international disparities in regulatory barriers to adoption can explain variations in technology adoption rates. On the other hand, appropriately designed regulatory and technology policies can stimulate technology adoption.

Geographic location may also be a significant driver of ICT adoption (Kelley and Helper, 1999). The potential adopter will only adopt the new technology if he or she has acquired the relevant information about the innovation's usefulness. The usefulness of an innovation is more likely to be observed in high population density areas where there are more people to observe and learn from, and where there are more people doing the observing and learning. The increased observability in high population density locations also reduces the level of uncertainty about the innovation. In addition, the size of the local market will influence the per capita cost of supply for producers. This may be of particular importance for certain ICT goods, such as Internet access, which require the provision of costly physical infrastructure. We can expect the higher per capita cost of service provision in lower population density areas to lead to higher prices and lower quality of service (Faulhaber and Hogendorn, 2001). The prevailing policy regime and the wider economic environment are also likely to influence rates and patterns of technology adoption. Certain communication goods are particularly susceptible to market failure, for example, because they are characterised by economies of scale with high fixed costs to build the network infrastructure and low marginal costs to service each additional user. Markets characterised by economies of scale and by network infrastructure tend to have high barriers to entry which can reduce or even preclude competition. The most efficient structure for such markets is often a monopoly (Posner, 1969). Where a market is controlled by a market player with significant monopoly power, the resulting lack of competition can lead to higher prices and lower quality of service. This is likely to inhibit the diffusion of the good or service. If a good or service is expected to generate positive externalities then there may be a case for direct government intervention to ensure market failure does not occur.

2.5 Broadband and Economic Growth

Why does the diffusion of broadband Internet matter for economic growth? Broadband is important for growth because it provides access to the World Wide Web and other online applications. This access increases the stock of knowledge available to any given individual. Broadband also matters for growth because it reduces the barriers and costs associated with accessing knowledge. Both of these characteristics of broadband facilitate the diffusion of the global stock of knowledge and increase the probability of a randomly chosen individual exploiting a randomly chosen idea for economic or other advantage. Nathan Rosenberg (1974) describes how the cost of knowledge is the main determinant of the rate of innovation. Knowledge is neither freely available nor omnipresent and Rosenberg argues that every innovation or incremental advance in the stock of knowledge has its own cost of production. The incentive for engaging in innovation activities will increase if the cost of producing or acquiring an innovation falls without a commensurate decline in the benefits of the innovation. Paul Romer (1990) describes how ‘influencing the cost of finding new ideas’ is the key to economic growth. If Rosenberg and Romer are correct then the significance of broadband for economic growth is straightforward. Broadband reduces search costs associated with ‘finding’ new knowledge and through this mechanism increases the long-run rate of growth.

The importance of broadband can also be explained by imagining the economy as a system consisting of multiple elements and connections. The elements within the system are the individuals and organisations and these elements are characterised by bounded rationality (Kahneman, 2003). The number of potential innovations within the system is virtually unlimited and technological progress is the outcome of new combinations of concepts and ideas. Each element possesses its own finite and unique set of ideas at any one time and these individuals and organisations learn and acquire knowledge from each other. One implication (Cowan, 2004) is that densely interconnected systems will generate a higher rate of innovation than sparsely connected systems. Access to the Web increases the density of connections within the economic system by providing new communications platforms and environments for connecting the different elements (Johnson, 2010). The total number of combinations of ideas available for discovery by any given element will increase when the connectivity of the elements is enhanced through a medium such as the Web. Broadband Internet provides easy access to a virtual platform which causes the density of the system to dramatically increase. By enhancing the density of the system in this manner broadband enhances the rate of innovation and long-run growth.

The empirical link between broadband and economic growth has not gone unchallenged despite the seemingly strong theoretical relationship. In particular, Robert Crandall (2010) expresses concern about the quality of much of the existing empirical work examining the link between broadband and growth. He argues that rather than demonstrating a relationship between broadband use and growth, many of the studies may simply be showing a greater demand for broadband in high-growth areas. Shane Greenstein and Ryan McDevitt (2009) have contested the claim that substantial economic value will be created by upgrading dial-up infrastructure to broadband. They argue that many of the reports extolling the economic value of broadband use implausibly outsized estimates and are both flawed and dangerously misleading. Despite these criticisms the limited amount of empirical work undertaken thus far does appear to suggest a positive link between broadband and growth (see Table 2.1).

Table 2.1: Selected studies examining the link between broadband and economic development

Forecast studies:	**General Finding**
Ferguson (2002)	Estimated failure to improve US broadband performance would restrict US productivity growth by over 1 per cent per year
Pociask (2002)	Estimated 1.2 million jobs would be created in the US through the development and use of a national broadband network
Crandall and Jackson (2001); Crandall, Jackson and Singer (2003)	Forecast broadband would provide an economic impact of $500 billion to US GDP by 2006
Katz (2009)	Forecast positive employment effects associated with increased broadband penetration in Latin America
Katz, Vaterlaus, Zenhausern and Suter (2010)	Estimated that for each €1 invested in broadband deployment there will be €2.58 generated in increased economic output
Crandall and Singer (2010)	Estimate $182.5 billion of capital investments in broadband infrastructure between 2010 and 2015 would increase US GDP by $542.1 billion
Empirical studies:	**General Finding**
SNG (2003); Kelley (2003); Ford and Koutsky (2005	All found positive economic impacts from investment in broadband
Gillett, Lehr, Osorio and Sirbu (2006)	Estimate broadband access and penetration causally enhances economic growth and performance
Goolsbee and Klenow (2006)	Calculate the consumer surplus from the Internet may be two per cent of full-income or several thousand dollars per worker
Crandall, Lehr and Litan (2007)	Found employment in several industries, for example finance, education and health care, is positively related to broadband penetration
Shideler, Badasyan and Taylor (2007)	Results suggest broadband availability increases employment growth in some industries but not others. Areas with poor broadband infrastructure will benefit more from investment than areas with already strong infrastructure
Koutroumpis (2009)	Found positive and statistically significant causal relationship between broadband and economic growth, especially when critical mass of infrastructure is present
Katz and Avila (2010)	Estimate a 1 per cent increase in broadband penetration yields a 0.0178 point contribution to GDP growth
Czernich, Falck, Kretschmer and Woessmann (2011)	Found a 10 percentage-point increase in broadband penetration raises annual per capita economic growth by 0.9 to 1.5 percentage points
Greenstein and McDevitt (2011)	Find the scale of the bonus obtained by countries investing in broadband is positively related to the size of the broadband economies in those countries.
Rohman and Bohlin (2012)	Find statistically significant relationship between broadband speed and economic growth. Estimate doubling the mean broadband speed in the OECD will contribute 0.3 per cent to growth compared to growth in the base year.

2.6 Conclusion

One of the principal goals of economic policymakers is to achieve improvements in material well-being. In the absence of continuous change the economy will eventually stagnate and the rapid growth in per capita output which has characterised the last two centuries will come to a halt. The standard of material wellbeing for the majority of people living in the West today is superior in almost every respect to the living standards of even the wealthiest people just one hundred years ago. A simple consideration of developments in health, nutrition, education, communication, transport and entertainment bears out this claim. The improvements in living standards are the result of on-going technological change and scientific progress. By advancing human knowledge we can continue to wrench free the secrets of nature and unlock more of Romer's infinite combinations. If knowledge is indeed power; as Bacon described it, then it is also emancipation. The implication here is not that governments should try and pick technological winners - nor is there an implication that government should necessarily engage in the direct production of new technologies. Rather the implication is that governments should strive to provide an institutional and socio-economic environment which supports and nurtures the production, development and diffusion of economically useful ideas and innovations.

However, Charles Goodhart (1975) and Robert Lucas (1976) emphasise the difficulties inherent to economic policymaking. For example, they argue that it is much too simplistic to try to predict the effects of a change in economic policy entirely on the basis of historically observed relationships. Relationships that appear to hold in the economy can change in response to changes in economic policy. If a new policy alters the incentives and opportunities presented to rational or bounded rational agents, then the new policy will also alter the behaviour of those agents. Such behavioural changes are difficult to predict in advance and make policy outcomes uncertain. Although policymakers cannot fully control or predict outcomes it would be overstating to suggest they are powerless to influence outcomes. How can policymakers encourage the production and diffusion of new technology? Given the potential underproduction of new technology by the private market the standard responses of most governments have been to incentivise private sector R&D and/or to engage in direct government investment in R&D. Common policies include the awarding of patents as well as the provision of fiscal subsidies and tax breaks. The public sector directly invests in R&D through the creation and support of research institutions such as universities, and invests indirectly through expenditure on R&D inputs such as human capital. Policymakers can also try and incentivise the production and diffusion of innovations through measures to increase the productivity of R&D and other knowledge production activities. This can be achieved by reducing the cost of innovation inputs or by improving the quality and efficiency of those inputs. One way to increase the productivity of knowledge production is to invest in human capital. This is because human capital is a complement to the production and exploitation of ideas. A second way to increase the productivity of knowledge production is for governments to support and invest in those technologies which themselves reduce the cost of knowledge search and the diffusion of useful ideas. This brings us to broadband.

While investment in certain forms of infrastructure, for example roads, may only provide a once-off shift in productivity (Fernald, 1999) investment in broadband infrastructure may permanently boost the annual rate of innovation and therefore permanently boost the rate of productivity growth. The flip side is that poor quality broadband infrastructure and low penetration rates may contribute to lower rates of growth. The industrial revolution which erupted in the eighteenth century has evolved into an information revolution. Broadband technologies are keystone technologies in this information revolution and in recent years Internet access technologies have become increasingly pervasive as inputs into the process of technological change. This has happened because Internet technologies greatly increase the productivity of knowledge search and R&D. They do so because they provide access to the main platform for the information revolution – namely the World Wide Web. To illustrate this consider individuals and organisations as elements within the economic system. Systems in nature excel at producing innovations where there is a strong capacity in the system for elements to make new connections with other elements and where there is a ‘randomising’ aspect to the environment that encourages collisions between two previously unconnected elements (Langton, 1992). The Web provides just such a platform and in so doing fundamentally changes the nature and density of knowledge flows within the economic system (Johnson, 2010). Some environments hamper innovation, by contrast, the environment of the Web is like an engine of innovation that generates information flows along multiple and unpredictable paths and increases the exposure of individuals and organisations to different people and to different ideas. Each of these new information flows and connections formed has a non-zero chance of generating a new innovation (Johnson, 2010). In this way the Web transforms the innovation process and drives economic change.

Internet access technologies are therefore qualitatively different to ordinary technologies and the broadband market is of far greater consequence to long-term growth than the vast majority of other product and service markets. This justifies and motivates the focus of the remaining chapters on broadband diffusion. In the next chapter I consider the development of the broadband market in Ireland and compare Ireland's broadband outcomes to that of other OECD countries. When considered in combination, chapter two and chapter three provide the motivation for the empirical work that follows in chapter four, chapter five and chapter six.

Chapter Three: Broadband Policies and Market Development

3.1 Introduction

The previous chapter discussed General Purpose Technologies (GPTs), broadband’s status as a GPT, and the significance of broadband and broadband market development for long-run economic growth. In this chapter I describe the technology platforms underlying broadband service provision and the implications for likely broadband market structures. I also describe the most common forms of policy intervention in broadband markets in the OECD and then consider explanations for Ireland’s trailing of the OECD across the major broadband market indicators such as availability, penetration, price and speed.

Broadband quality Internet access is most commonly obtained in the majority of OECD countries via Digital Subscriber Line (DSL) technology. DSL is high frequency digital data transmission over the copper lines of the telephone network. In the fixed-line broadband market DSL’s main rival technologies are cable and optical fibre. The market for provision of fixed-line broadband has natural monopoly characteristics, for example high fixed costs and low marginal costs (Faulhaber and Hogendorn, 2001). The Irish telecommunications regulator Comreg has described the main DSL service provider Eircom PLC as having significant market power in the Irish fixed-line market (Comreg, 2010, pp 7-8). However, the fast moving nature of advancements in broadband technology, for example in wireless technologies, suggests broadband market structures are likely to change in the future. Broadband policy in the OECD has heavily emphasised the importance of competition in the broadband market (Ferguson, 2004; OECD, 2008b). A common regulatory strategy used to generate greater competition in the DSL market is to require the dominant market player (known as the incumbent) to lease the local loops of its network infrastructure to competitors. This process is known as Local Loop Unbundling (LLU). However, forcing the incumbent to open its network to greater competition may be counterproductive in the long-run because it disincentives investment by the incumbent in its broadband infrastructure (De Bijl, 2005). Other strategies to encourage the development of the broadband market include direct government subsidies, fiscal incentives such as tax breaks, the guarantee of direct government purchases of broadband services, public private partnerships to stimulate investment in network infrastructure, and incentives to stimulate private demand for broadband (Belloc, Nicita and Rossi, 2011).

The main indicators used to evaluate the broadband market are the broadband coverage and penetration rates, both of which are proxies for broadband diffusion. In addition, broadband speed and reliability indicate the quality of broadband available; while broadband price is a measure of value for money and can be seen as a proxy for competition, affordability and market development. Ireland trails the OECD across each of the main broadband market indicators (OECD, 2011). Ireland ranked 25th out of 34 OECD countries for broadband penetration in 2011. Ireland's penetration rate has trailed the OECD since broadband was originally introduced in the OECD countries. Weak competition, lack of investment, and adverse population characteristics such as low population density have all variously been advanced as reasons for Ireland's comparative underperformance. Competition in the Irish DSL market has been inhibited by the low levels of LLU in Ireland compared to the OECD (ECTA, 2011). Investment levels in Eircom's network infrastructure have also been low, particularly in the critical early years of broadband's diffusion between 2002 and 2004 (Palcic and Reeves, 2011). Lower levels of investment means reduced coverage and lower quality of service. Eircom's financial difficulties, which are largely a function of two highly leveraged buy-outs, can explain the lack of investment in the DSL network. However, Eircom's problems cannot explain the slow development of the competing cable network which also trails the OECD in terms of penetration. In addition, Ireland's low population density and high population dispersion reduces the commercial case for investment in broadband infrastructure and suggests targeted intervention may be required to prevent failure in the next generation broadband market.

3.2 Broadband Technology Platforms

The broadband market arose out of the commercialisation of the Internet in the mid-1990s (Hedge, 2006) and the subsequent co-development of broadband supply and broadband demand. The functionality of the Internet rapidly increased in the wake of its commercialisation as more and more content, applications and services developed over time, for example, online newspapers, auctions and banking. The increasing data transmission requirements needed to fully exploit the growing functionality of the Internet fed a growing consumer demand for faster and more reliable Internet access. Broadband Internet has two key advantages over more traditional dial-up narrowband Internet. Broadband has faster download and upload speeds than dial-up, and unlike dial-up, broadband does not require the exclusive use of the line. The download transmission speed is the speed of data transfer from the service provider to the business or household, whereas the upload transmission speed is the speed of data transfer in the opposite direction. Broadband is defined by Bauer, Gai, Kim and Wildman (2003) as a set of general-purpose electronic communications technologies, with common features such as significantly higher bandwidth than dial-up networks, a reliance on packet switching, and always-on functionality. Robert Crandall (2005) and Martin Fransman (2006) focus primarily on speed and always-on functionality as the key defining characteristics of broadband, with Fransman distinguishing broadband from traditional dial-up narrowband in terms of the significantly faster instant access it provides.

There is no internationally uniform cutoff point distinguishing broadband bandwidths from slower bandwidths. For example, the OECD (2006) regarded download speeds equal to or faster than 256kbits/s as broadband in 2006, while in the same year the International Telecommunications Union (ITU), which is the United Nations agency for information and communications technologies, defined speeds equal to or faster than 256kbits/s in *either* direction as broadband (ITU, 2006, p.11). In 2008, the Federal Communications Commission (FCC), the telecommunications regulator for the United States, regarded data transmission speeds as slow as 200 kbits/s in either direction as broadband (FCC, 2008) while the minimum requirement to be considered broadband according to the National Broadband Scheme of Ireland’s Department of Communications was 1Mbits/s download and 128kbits/s upload (DCENR, 2008). By 2011, the ITU only regarded download speeds in excess of 1.5 Mbits/s to 2Mbits/s as broadband. Minimum transmission speeds for state-of-the-art data services are likely to continue increasing and given past trends the official definitions of broadband are likely to remain a moving target. Rather than defining broadband in terms of minimum transmission speeds it may be more useful to define broadband as Internet access sufficient to ensure high-quality access to state-of-the-art Internet applications.

The provision of broadband services on a widespread basis, and via a range of technology platforms, has increasingly become a viable commercial possibility due to technological advances in telecommunications over the last twenty years. The most common technology platforms for the commercial provision of broadband are categorised in Table 3.1. The nature and variety of commercially viable broadband technologies has implications for likely broadband market structures and therefore for broadband policy.

Table 3.1: Common broadband access platforms

Technology Platform	**Shorthand Title**	**Method of Transmission**	**Fixed/Wireless**
Digital Subscriber Line	DSL	Copper wiring infrastructure of the telephone network	Fixed
Coaxial Cable Modem	Cable	Copper wiring infrastructure of the cable television network	Fixed
Optical Fibre	Fibre or FTTX	Optical fibre upgrade of copper wiring infrastructure	Fixed
Terrestrial Fixed Wireless	FWA	Radio signals to a fixed point	Wireless
Mobile Broadband	Mobile	Portable modem	Wireless
Satellite Uplink	Satellite	Geostationary low orbit satellite to a fixed point	Wireless

Fixed wire technologies and natural monopolies

Multi-firm production or provision of services will be more costly than production or provision by a single entity where the industry or service is a natural monopoly. William Baumol (1977) describes natural monopolies as markets characterised by network infrastructure, by high fixed costs, by high barriers to entry, by economies of scope and scale, and by low or zero marginal cost. Richard Posner defines natural monopolies as follows:

> A natural monopoly does not refer to the actual number of sellers in the market but to the relationship between demand and the technology of supply. If the entire demand within a relevant market can be satisfied at lowest cost by one firm rather than two or more, the market is a natural monopoly (Posner, 1969, p.548).

Allowing a monopoly to persist can be justified where competition cannot effectively be made to work in the sector and where a single service provider is the most efficient market structure. The provision of fixed-line broadband is characterised by the high fixed costs required to build the network infrastructure and by the low marginal costs involved in connecting new customers to the network and then subsequently supplying those customers with additional services. This cost structure suggests that fixed-line broadband is a natural monopoly. The high fixed costs required to build a large network infrastructure constrains the ability of competitors to offer alternative services. Gerald Faulhaber and Christiaan Hogendorn (2001) have modelled broadband market structures. Their models suggest the exact market structure will depend on population density and that below a certain population density the broadband market will be a natural monopoly. Therefore policies aimed at maximising competition in broadband markets, at least in low population density areas, may not be consistent with achieving economically efficient outcomes.

Fixed wire technologies: DSL broadband

Digital Subscriber Line (DSL) technology is the dominant platform in Ireland's fixed-line broadband market. DSL is also dominant in the majority of other OECD countries. Almost 78 per cent of fixed broadband connections in Ireland were DSL connections at the end of 2010 while over 21 per cent were cable broadband connections. The equivalent figures for the OECD were just under 58 per cent for DSL and over 29 per cent for cable (OECD, 2011). DSL broadband is high frequency digital data transmission over the copper lines of the telephone network. DSL uses the same wires as the telephone system and in most OECD countries the owner of the telephone network has gone on to become the dominant DSL provider. DSL bridges the 'last mile' from the Internet service provider's network infrastructure to the subscriber's premises, and it operates by dividing the frequencies used within a single phone line into two separate frequency bands. The Internet modem and the telephone equipment can be used simultaneously by installing a DSL filter to separate out the high frequency transmissions used for Internet services from the low frequency transmissions used for telephone services (Bourne and Burstein, 2001). The dominant DSL provider in Ireland is Eircom plc. Eircom is the former state owned telephone network operator which became fully privatised in 1999. The DSL market has natural monopoly characteristics in so far as it is based on network infrastructure with high fixed costs and low marginal costs. Ireland's telecommunications regulator Comreg has stated Eircom holds significant market power in the DSL as well as in the fibre broadband markets (Comreg, 2010). Monopoly in the DSL market is not inevitable. One way to increase competition is to enforce Local Loop Unbundling (LLU). LLU stimulates intra-platform competition in the DSL market by requiring the incumbent carrier to lease the local loop of its network to competitors. The local loop connects the telephone exchange to the subscriber's premises and LLU obligations enable competitors to offer services to broadband customers over the last mile of the network without having to construct their own backbone networks. Official Irish policy requires Eircom to unbundle its local loops to other broadband service providers. However, Ireland has a very low rate of LLU compared to most other OECD countries and has the lowest rate in the EU15 (ECTA, 2011).

Fixed wire technologies: cable broadband

Cable broadband is the second most common form of fixed wire broadband subscription in Ireland and in the OECD (OECD, 2011). It is the most common type of broadband subscription in the United States and Canada. Cable typically provides faster speeds than DSL. UPC is the cable broadband provider in Ireland and it has the second largest share of the fixed broadband market after Eircom.Cable broadband systems are capable of operating at distances of up to 160 kilometres from the operator to the customer's modem and access is provided to a broadband data signal over the cable television infrastructure (Franklin, 2011). A cable modem requires a coaxial cable of greater thickness than the basic cable television line as well as sufficient insulation from electromagnetic interference. The system allows for the simultaneous passage on the TV cable of triple-play services (voice, data and television) and data access is obtained by utilising bandwidth unused by the television network (Franklin, 2011). Cable broadband shares the same natural monopoly characteristics as DSL broadband including high fixed costs and low marginal costs.

Fixed wire technologies: fibre broadband

Optical fibre lines provide a more efficient and faster means of transmitting data than copper lines (Hecht, 2004). FTTX is the generic term used to describe the deployment of fibre-optic cables for broadband (Keiser, 2006). The fibre cables are connected to a platform known as a cabinet and this cabinet then serves several consumers within a geographic location. The consumer is usually connected over the last mile of the service by copper wire infrastructure.

The closer to the customer's premises the cabinet is deployed, the higher the costs of providing the service, but also the higher the potential speed. The fastest although most expensive version of fibre deployment is Fibre To The Home (FTTH). FTTH involves deploying the optical fibre right up to the subscriber's premises (FTTH Council, 2006). Although it is the dominant technology in Japan and Korea, fibre access is far less widespread for broadband service provision than either DSL access or cable access in almost every other OECD country. Despite being capable of far higher speeds than either DSL or cable, FTTX makes up less than 1 per cent of broadband subscriptions in Ireland (OECD, 2011). One explanation is the very high fixed costs associated with deploying fibre optic infrastructure. The incumbent telephone and cable television companies (Eircom and UPC) were already in possession of extensive copper-based network infrastructures at the beginning of the broadband era. It was therefore substantially cheaper for them to continue using their existing copper infrastructures rather than building new fibre-based networks. DSL, cable and fibre are all shared access technologies meaning users in a particular geographic area must share the transmission capacity of the broadband infrastructure. The speed of fixed-line services vary because speed depends on the number of users currently on the line, the quality of the line, and the distance of the premises from the nearest exchange.

Wireless technologies

Broadband Internet access can also be obtained via wireless based technologies, namely Fixed Wireless Access (FWA), mobile broadband, and satellite broadband. Wireless technologies do not have the same infrastructural costs and barriers to market entry as fixed-line technologies. However, wireless broadband is usually slower and less reliable than fixed-line broadband (Cave and Hatta, 2009). Advances in the reliability and speed of wireless technology may in the future lead to wireless becoming a fully functional substitute for fixed wired broadband, for example through the development of 4G technology. If this happens, monopoly concerns in the market for broadband service provision will decline. FWA uses licensed radio spectrum to deliver a point-to-point connection from the service provider to a stationary fixed place device such as a desktop computer (Trinkwon, 1996). Mobile broadband differs from FWA in that the data is transmitted to a portable device such as a mobile phone. Mobile broadband access is obtained through portable 3G devices such as USB modems, mobile data cards, or laptops with built-in broadband access. Satellite broadband access uses a satellite in low geostationary orbit to transmit data to a fixed device. The seventy thousand kilometre round trip causes a severe latency (delay) problem which makes satellite broadband unsuitable for many applications such as gaming and video conferencing. Nevertheless, satellite may be the only viable option in isolated rural areas where the commercial case for network deployment is particularly unfavourable.

3.3 Broadband Market Interventions

Policy interventions and considerations

Policymaking for the telecommunications sector is particularly difficult because of the complex and fast moving nature of technology induced changes in the sector. Richard Posner (1969) argues that as technology changes, a market may cease to be, or indeed may evolve into, a natural monopoly. Martin Fransman (2006, p.24) identifies the activities of “disruptive competitors” as an important determinant of broadband performance, while broadband policy internationally has emphasised the need to increase competition (Ferguson, 2004; OECD, 2008b). A common policy initiative to support intra-platform competition in the DSL market is to require the incumbent network operator to unbundle the local loop or “last mile” of its network. While such LLU policies may appear a promising method of generating competition for broadband service provision, the appropriateness of LLU policy appears to depend on the stage of market development. Orada Teppayayon and Erik Bohlin (2011) argue that there may be tension between investment and competition in telecommunications markets. Policies that tend to increase competition may actually reduce overall investment. As Jan Bouckaert, Theon Van Dijk and Frank Verboven put it:

> The common criticism against mandatory access is that there is a trade-off between static and dynamic efficiencies. While mandatory access may stimulate competition in the short-run at the retail level, it may reduce the incentives to invest in infrastructure, both by the incumbent, who is forced to share its network, and potential entrants, who can free-ride on the incumbent’s network (Bouckaert, Van Dijk and Verboven, 2010, p.664).

Therefore while cheap prices for use of the local loops may well stimulate competition in the short-run this may be at the expense of investment over the long-run.

Swadesh Samanta, Richard Martin, Ken Guild and Hui Pan (2011, p.7) note that regulation can be a balancing act between competition and investment. They argue that strong regulation such as mandatory unbundling and pricing provides little motivation for investment in infrastructure. Nevertheless, a literature review of empirical research articles on the relationship between regulation and investment did not conclude that strong unbundling regulation had a negative effect on investment (Cambini and Jiang, 2009). Raul Katz and Javier Avila (2010) point to an extensive literature emphasising the importance of regulatory variables for successful telecommunications market development. Regulatory variables comprise all those related to regulatory approaches including market entry regulation, price regulation, the regulatory process including proper market analysis, and the application and enforcement of regulation (Katz and Avila, 2010, p.7). Bouras, Gkamas and Tsiatos (2009) present a methodology for identifying best practice policies for supporting broadband growth. They identify a strong correlation between broadband penetration and the quality of the regulatory framework as measured by the ECTA's regulatory scorecard, and they argue that one reason Ireland does not have satisfactory broadband penetration is regulatory problems associated with the application of regulations due to lengthy appeals. Bouckaert, Van Dijk and Verboven (2010) analyse OECD data and their findings suggest that although inter-platform competition between DSL and cable has been a strong driver of broadband penetration, intra-platform competition in the DSL market has had essentially no effect on broadband penetration. They link this finding back to access regulation designed to stimulate competition in the DSL market and conclude:

> these findings...suggests that the "stepping stone" or "ladder of investment" theories might not provide the justification to impose extensive mandatory access obligations on DSL incumbents (Bouckaert, Van Dijk and Verboven, 2010, p1).

Paul De Bijl (2005) proposes full structural separation of the network operator from the retail market as a viable alternative strategy for generating competition and avoiding future market failure in the retail broadband market. Full structural separation entails completely separating ownership of the infrastructure network from the retail broadband market. The network operator, which may or may not be partially owned by the state, would then sell wholesale services to any number of competing retail companies. De Bijl (2005) provides an overview of structural separation. Inter-platform competition between technologies such as DSL and cable can be supported in a number of ways, for example through fiscal subsidies or through direct purchases by state agencies (OECD, 2008b). The multiplicity of technology platforms capable of supplying broadband access, combined with advances in wireless technology, may help reduce monopoly concerns in the future.

Charles Ferguson (2004) and Bouras, Gkamas and Tsiatos (2011) provide overviews of broadband policy models in different countries. Most OECD countries have intervened with supply side measures to support broadband market development. Japan, Korea, the United States, Spain and Norway have all used fiscal incentives and long-term loans to encourage private sector investment in broadband infrastructure (Belloc, Nicita and Rossi, 2011).

According to Teppayayon and Bohlin (2011), government funding for broadband expansion is stipulated by law in Sweden where the government undertakes special responsibility to stimulate broadband in areas where the public interest is not fulfilled by market forces. Supports include direct funding, subsidies of services and public-private partnerships (PPP). Korea and Australia have also adopted this approach. The EU has specifically changed its state-aid rules to facilitate public-private ventures in broadband infrastructure (Palcic and Reeves, 2011). The Netherlands, France and the United Kingdom have all used the PPP model to develop next generation fibre infrastructure, while New Zealand, Australia and Singapore have plans in place for joint ventures between the public and private sector.

Japan, Canada and Italy have all used demand-side policies to stimulate the broadband market, for example by providing on-line information for citizens and by acting as buyers and users of broadband technologies. Portugal, Greece and Hungary have tried to stimulate demand by subsidising the purchases of computers for various groups. Filippo Belloc, Antonio Nicita and Maria Rossi (2011) use a dataset of broadband policies, the International Broadband Policies Database (IBPD) covering 30 OECD countries over the period 1995-2010, to investigate an array of public policies on fixed wire broadband penetration. Regulatory measures were beyond the scope of the study. Belloc, Nicita and Rossi find that both supply-side policies and demand-side policies have a positive effect on broadband penetration, with the relative impact depending on the particular stage of broadband diffusion. The authors report that fostering market competition has a positive impact on broadband penetration, but also argue that demand-side and supply-side policies are complementary and more effective if taken together. The set of industrial policy interventions covered in the IBPD is shown in Table 3.2. The results of the study suggest that demand-side interventions are more effective at stimulating market development than supply-side interventions.

Table 3.2: International broadband policy measures – Industrial policy interventions

	Supply-side interventions		**Demand-side interventions**
1.	Adoption of fiscal incentives programs and subsidies	A.	Initiatives of *public demand* of specific services
2.	Implementation of long-term loans programs for broadband suppliers and national financing programs	B.	Provisions of incentives for *business demand*
3.	Creation of Public Private Partnerships with *public* ownership of the infrastructure network	C.	Provisions of incentives *for private demand*
4.	Creation of Public Private Partnerships with *private* ownership of the infrastructure network	D.	Provision of demand subsidies in favour of individual consumers or particular categories of consumers
5.	Implementation of territorial mapping programs	E.	Adoption of demand aggregation policies
6.	Initiatives of administrative simplification		

Source: Belloc, Nicita and Rossi (2011), figure 2, page 7

Prior to the 1980s the prevailing attitude was that the ideal market structure for telephone and other telecommunication services was a complete monopoly. This was because of the belief that increasing returns to scale could best be obtained by a single monopolistic supplier (Teppayayon and Bohlin, 2011, p.7). Most European Union member states have been liberalising their telecommunications markets since at least the release of the European Commission’s Bangemann Report in 1994 which strongly supported greater competition (European Commission, 1994). In a bid to minimise the possibility of broadband market failure, broadband policy in the European Union has attempted to enhance competition through liberalisation and privatisation. Positive effects of competition may include price reduction, better quality service and more effective resource allocation. Katz and Avila argue:

> ...if a country wants to develop high quality, highly deployed broadband services, it needs to stimulate the development of platform-based competition, strengthen the institutional framework to build an adequate set of checks and balances that guarantee sustainable competition, develop a government broadband plan, and allow for total foreign direct investment (Katz and Avila, 2012, p.19).

To what extent is broadband market failure likely in the future? Although the provision of telecommunication infrastructure has natural monopoly characteristics, it is nevertheless possible to transmit high frequency data over a number of different technology platforms, for example the telephone and cable television networks. As a result the market structure for wired broadband is actually closer to a natural oligopoly than a natural monopoly. However, wired broadband markets are characterised by scale effects and De Bijl (2011) argues that strong competition in the provision of broadband infrastructure is unlikely in the future because the high levels of investment required for the next generation of optical fibre networks will make competition between several networks unviable. If DeBijl’s argument is correct then market-driven policies of liberalisation and privatisation may not be sufficient to prevent market failure, particularly in areas of low population density. Competition may even reduce the level of investment in marginally profitable regions thereby exacerbating regional inequalities. The lack of attractiveness of rural areas for infrastructure investment raises the prospect of a ‘digital divide’ emerging between urban and rural residents in terms of future access to high-speed broadband (Preston, Cawley and Metykova, 2007). Possibilities for infrastructure-based competition will depend on local cost considerations and on scale effects. Ireland, particularly outside of the main cities, may be a particularly unpromising location for infrastructure-based competition because of the comparatively small, low-density and dispersed population. Paschal Preston, Anthony Cawley and Monika Matykova (2007) find that generally lower levels of infrastructure investment and competition prevails in rural areas. Possible supply-side policies to encourage operators to supply underserved areas, or to invest in next generation technology, include the use of tax incentives, fiscal subsidies, public private partnerships, or long-term loan programmes.

Policy interventions in Ireland

Ireland’s telecommunications infrastructure was under state ownership and control between its nationalisation in 1912 and its eventual privatization in 1999. The state has remained an important actor in the telecommunications market despite the privatization of the network. According to Forfás, the Irish Government’s policy advisory board for enterprise, trade, science, technology and innovation:

> Advanced broadband services are crucial to achieve the productivity growth necessary to improve competitiveness, sustain high-level incomes and ensure Ireland captures new opportunities for entrepreneurship and jobs across all sectors (Forfás, 2011, p.1).

However, Forfás (2011, p. 2) expresses concern that: “...Ireland lags other EU countries and those with which we compete for trade and investment in the provision of widely available competitively priced, advanced broadband”. In addition to pursuing LLU policies to enhance competition, the Irish Government has intervened on a number of occasions to aid the provision of broadband services to commercially unviable or marginal locations (Forfás, 2011; Palcic and Reeves, 2011). The most significant state interventions have been to address the urban/rural digital divide phenomenon. The digital divide is the phenomenon whereby rural areas tend to severely lag their urban counterparts due to the much higher per capita costs required for infrastructure provision (Skerratt, 2005). The Western Development Commission argued that “...the availability of quality telecommunications infrastructure and services at a competitive price is as crucial to regional development today as rural electrification was in the 1940s and 1950s” (WDC, 2002, p.5).

The main Irish state interventions are described in Table 3.3 and include the Metropolitan Area Networks (MANS) project designed to accelerate the provision of services outside Dublin; the Group Broadband Scheme (GBS) designed to encourage internet service providers to provide broadband access to communities of less than 1,500 people; and the National Broadband Scheme (NBS) designed to deliver broadband to certain target areas deemed to have insufficient broadband services. In 2011 the government convened a taskforce comprising the CEOs of all of the major telecommunications companies currently operating in the Irish market and tasked with devising strategy for next generation broadband roll-out in Ireland (Merrion Street, 2011). The taskforce made a total of fifty one recommendations (DCENR, 2012a) calling for greater access to, and use of State entities and assets, as well as policies to support demand stimulation and infrastructure barrier removal. In September 2012 the government announced the National Broadband Plan (NBP). The goal of the NBP is to ensure high speed (30Mbps) broadband for all by 2020 and speeds of at least 70Mbps for half the population by 2015. It is intended that the NBP will be co-funded by the state with additional finance obtained by leveraging investment from the public and private sector (DCENR, 2012b).

Table 3.3: Irish Government interventions in the broadband market

Year	Programme	Purpose	Description
2003	Metropolitan Area Network (MANS)	Reduce barriers to entry for new operators in regional towns	Provision of open access fibre infrastructure linking the national backbone network to the local access network – 90 per cent grant-aided by the state (remainder coming from the EU)
2004	County & Group Broadband Scheme (CGBS)	Subsidise provision of broadband to rural areas and small towns	Partnership with local communities - the state providing 55 per cent of the required capital funding (maximum allowable under EU rules)
2007	National Broadband Scheme (NBS)	Subsidise provision of broadband to currently un-serviced rural areas to address 'digital divide' issues	Partnership with 3G networks to provide mobile broadband to rural areas - part-financed by the exchequer
2012	National Broadband Plan (NBP)	Provide high speed broadband (30Mbps) to all by 2020 and speeds of 70Mbps to half the population by 2015	Leverage investment from both the public and private sectors - co-funding of €175million to be provided by the State (50 per cent)

Sources: Department of Communications, Marine and Natural Resources, 2003; Skerratt, 2005; Forfás, 2011; Palcic and Reeves, 2011; Department of Communication, Energy and Natural Resources, 2012b.

3.4 Broadband Market Indicators

At the end of the second quarter of 2011 there were 1.63 million broadband subscriptions in Ireland across all technology platforms (Forfás, 2011, p.3). Ireland compares poorly to the OECD and to the EU across a range of broadband indicators including broadband penetration, speed and cost. Ireland's fixed-line broadband penetration rate has remained in the bottom half of OECD countries since the broadband diffusion process began in Ireland in the early years of the twenty first century. According to Forfás (2011, p 18) by the end of June 2011 Ireland had 21.1 fixed-line subscribers per 100 inhabitants compared to the OECD average of 27.3. In January 2012 the European Commission (2012a, p.10) estimated fixed-line broadband penetration in Ireland was 24.3 per cent, which was lower than the EU penetration rate of 27.7 per cent. Ireland has a higher wireless mobile broadband subscription rate than the average rates in both the EU (European Commission, 2012a, p.39) and the OECD. However, mobile broadband tends to be of lower speed and reliability than fixed broadband (Cave and Katta, 2009). It is highly debatable whether wireless mobile broadband offers a truly equivalent service to fixed-line broadband. Broadband speeds in Ireland are relatively low (Forfás, 2011, p.20; European Commission, 2012b) compared to other EU countries, while prices are relatively expensive (OECD, 2011, Table 4C).

Scoreboards and Indicators

In chapter two we discussed how the economic impact of a technology depended on the technology’s diffusion through the economy. A number of international organisations regularly compile scoreboards of broadband diffusion and of broadband market development in general. For example, the OECD produces a set of broadband indicators for its member countries on a quarterly and annual basis (OECD, 2011), while the European Competitive Telecommunications Association (ECTA, 2011) and the International Telecommunications Union (ITU, 2012) produce indicators for a wider group of countries. The most commonly used indicators of broadband development are described in Table 3.4. Broadband penetration is useful as an indicator of, and proxy for broadband diffusion, while broadband coverage is a useful indicator because it represents the maximum level of broadband adoption at any given time as well as the current geographic extent of broadband supply. Broadband price is an indicator of broadband affordability and may also indicate the level of competition in the market for broadband service provision. Broadband speed is an indicator of broadband quality. Higher speeds make possible a larger number of applications and services.

Table 3.4: Key indicators of broadband market development

Indicator	Unit of measurement
Penetration rate	The number of active subscriptions per 100 people
Coverage rate	The proportion of the population with the option to purchase affordable broadband
Price	The monetary cost per Mbit/s
Speed	Usually measured by the fastest, and median, download speeds offered by the major DSL and cable operators

Measuring broadband diffusion: the penetration rate

The active broadband subscription rate per 100 people, known as the broadband penetration rate, is an indicator of the level of broadband diffusion in the population. It measures the number of active physical connections being provided by operators to consumers. However, the penetration rate should only be considered a proxy for the actual number of broadband users. For example, two countries with identical subscription rates may actually have very different user rates simply due to differences in average household size (see Forfás, 2011; Ford, 2011). A country with an average household size of two people implies there are up to two broadband users per physical connection, while a country with an average household size of six may have up to six broadband users per physical connection. Ireland has consistently maintained a lower penetration rate than the OECD since the beginning of the broadband diffusion process. Table 3.5 shows the rates for fixed-line broadband subscriptions by technology platform in the OECD at the end of 2010 (OECD, 2011). Ireland’s fixed penetration rate at the end of 2010 was 21.1 broadband subscriptions per 100 inhabitants, which was the 10th lowest out of 34 countries. Ireland’s penetration rate was lower than the weighted and unweighted averages for the OECD. These averages stood at 24.9 and 25.9 subscriptions per 100 inhabitants. The unweighted average for the EU15 was 28.5 subscriptions at the end of 2010. Ireland is the only one of the 10 countries with the lowest fixed-line penetration rates to have a higher per capita income than the OECD average. Ireland has the third lowest fixed-line broadband subscription rate in the EU15. Only Portugal and Greece have lower rates.

Over three quarters of fixed-line broadband subscriptions in Ireland are DSL connections (77.7 per cent). The equivalent rate for the OECD is 57.4 per cent of all subscriptions. Therefore DSL is even more dominant as a technology platform in Ireland than it is in the OECD. DSL is the most important fixed-line technology platform in every EU15 country and access via DSL comprises over 50 per cent of fixed-line broadband subscriptions in 28 of the 34 OECD countries. Hungary and Estonia are the only countries where no single technology platform holds a 50 per cent or higher market share. Optical fibre is the dominant platform in the high population density countries of Korea and Japan while cable is the most widespread platform in Canada and the United States. One reason for cable's dominance in these two countries may be the tough LLU requirements imposed by national regulators on the incumbent telephone network operators (Hausman, 2002). The tough regulatory requirements would have reduced the regional incumbents' incentives to upgrade and expand their networks and may have made it more difficult for them to compete.

Table 3.5: Fixed-line broadband penetration in the OECD at December 2010

Rank	**Country**	**Total**	**Platform**				
			DSL	***Cable***	***Fibre/LAN***	***Other***	***DSL (% of total)***
1	Netherlands	38.1	21.6	15.4	1.1	0.0	56.7
2	Switzerland	38.1	26.6	10.6	0.3	0.5	69.8
3	Denmark	37.7	22.3	10.1	4.7	0.7	59.2
4	Norway	34.6	19.3	9.8	5.4	0.1	55.8
5	Korea	34.0	5.0	10.2	18.8	0.0	14.7
6	France	33.7	31.5	1.9	0.2	0.0	93.5
7	Iceland	33.7	30.0	0.0	3.6	0.0	89.0
8	Luxembourg	33.5	28.3	4.9	0.2	0.1	84.5
9	UK	31.9	25.1	6.6	0.2	0.0	78.7
10	Germany	31.9	28.1	3.5	0.1	0.1	88.1
11	Sweden	31.8	17.0	6.4	8.4	0.1	53.5
12	Belgium	30.8	16.9	13.9	0.0	0.1	54.9
13	Canada	30.7	13.3	17.2	0.1	0.0	43.3
14	Finland	28.6	20.7	4.5	0.4	3.0	72.4
15	United States	27.7	10.9	15.0	1.6	0.2	39.4
16	Japan	26.7	6.7	4.5	15.5	0.0	25.1
17	New Zealand	24.9	23.4	1.4	0.1	0.0	94.0
18	Australia	24.1	20.0	4.0	0.1	0.0	83.0
19	Israel	24.0	14.1	9.9	0.0	0.0	58.8
20	Austria	23.9	16.7	7.0	0.1	0.1	69.9

Note: Measures total fixed-line broadband subscriptions per 100 inhabitants (by technology), December. 2010. Figure shown for the OECD as a whole is a weighted average; Unweighted average for the OECD is 25.9. Original data is supplied by the national governments except data for the United States which is an OECD estimate. Table continues on the next page.

Sources: OECD Broadband Statistics 2011, Table 1D (1);

Table 3.5 (continued): Fixed-line broadband penetration in the OECD at December 2010

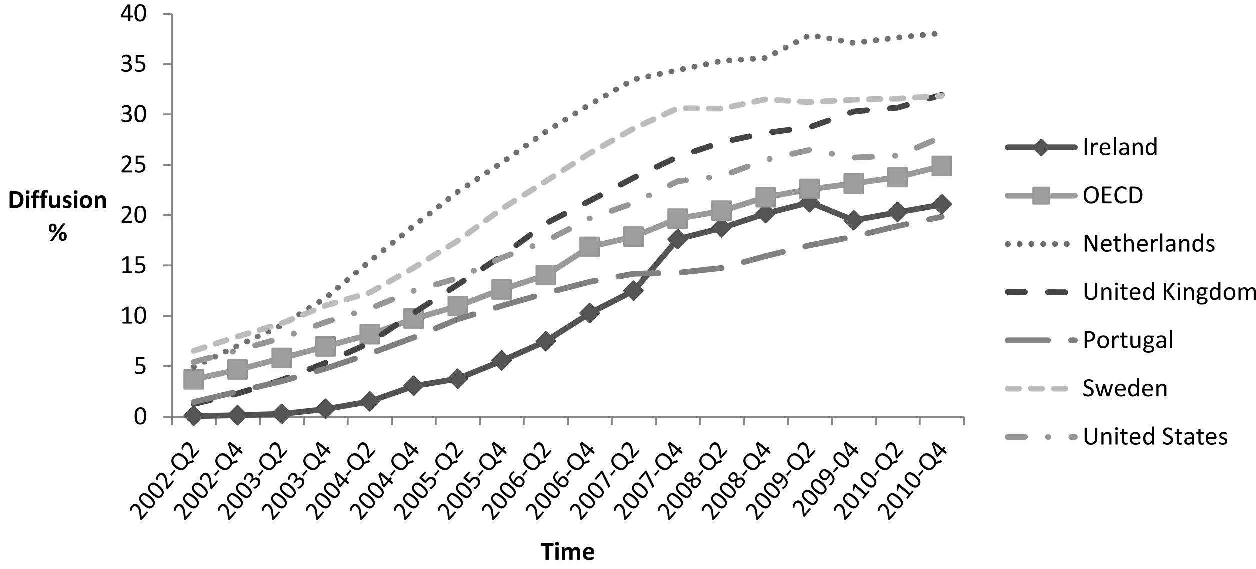
Rank	**Country**	**Total**	**Platform**				
			DSL	***Cable***	***Fibre/LAN***	***Other***	***DSL (% of total)***
21	Slovenia	23.8	13.9	6.0	3.8	0.0	58.4
22	Spain	23.4	18.9	4.3	0.1	0.0	80.8
23	Estonia	23.3	11.0	5.6	5.3	1.4	47.2
24	Italy	22.1	21.6	0.0	0.5	0.0	97.7
25	**Ireland**	**21.1**	**16.4**	**4.5**	**0.1**	**0.0**	**77.7**
26	Greece	19.9	19.8	0.0	0.0	0.0	99.5
27	Portugal	19.8	10.5	8.1	1.2	0.0	53.0
28	Hungary	19.6	8.2	9.0	2.4	0.0	41.8
29	Czech Rep.	14.7	8.2	4.8	1.7	0.0	55.8
30	Poland	14.2	8.1	4.4	0.2	1.5	57.0
31	Slovak Rep.	12.8	7.3	1.7	3.7	0.0	57.0
32	Mexico	10.4	8.3	2.0	0.0	0.1	79.8
33	Chile	10.4	5.4	4.9	0.0	0.0	51.9
34	Turkey	9.8	9.1	0.4	0.2	0.0	92.9
	OECD	24.9	14.3	7.3	3.1	0.2	57.4

Note: Measures total fixed-line broadband subscriptions per 100 inhabitants (by technology), December. 2010. Figure shown for the OECD as a whole is a weighted average; Unweighted average for the OECD is 25.9. Original data is supplied by the national governments except data for the United States which is an OECD estimate.

Sources: OECD Broadband Statistics 2011, Table 1D (1);

Figure 3.1 tracks the diffusion of fixed-line broadband in Ireland over time. Broadband diffusion in Ireland between 2002 and 2009 broadly mirrors the S-shaped diffusion process anticipated by the diffusion models described in chapter two. The downward spike in subscriptions in the fourth quarter of 2009 is explained by the OECD’s decision from that point onwards to exclude Fixed Wireless Access (FWA) and access obtained via satellite from the OECD measurement of the penetration rate. Ireland has the fifth highest penetration rate for FWA in the OECD. When considered in aggregate, the diffusion path for the OECD only somewhat exhibits the expected S-shaped curve. This is because the diffusion curve for the OECD actually represents the aggregate of thirty four overlapping diffusion processes. The diffusion process began as early as 2000/2001 in some countries but was delayed until as late as 2003/2004 in other countries.

Figure 3.1: Tracking fixed-line broadband diffusion in the OECD

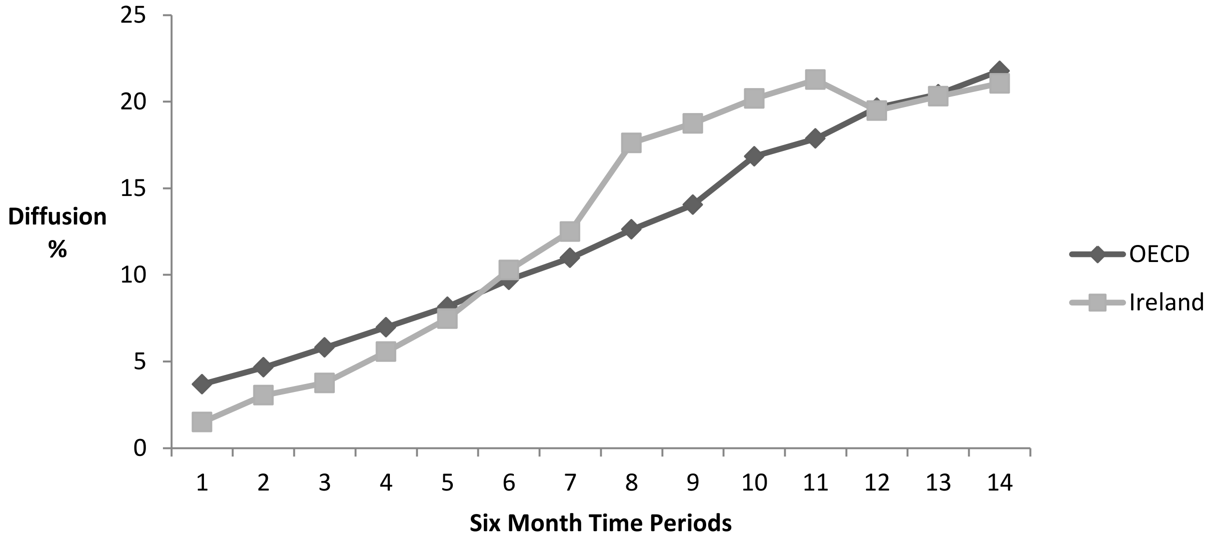


Note: The vertical axis represents the broadband subscription rate per 100 persons and the horizontal axis represents the time period (e.g. Q2 2002 represents the end of the second quarter of 2002). FWA and Satellite were included in the OECD calculations up until June 2009 but were excluded from December 2009 onwards (2009-Q4).

Source: OECD broadband statistics 2011, Table 1G;

Ireland's low penetration rate relative to the OECD does not appear to be a function of lower annual growth rates in the number of broadband subscriptions. The number of fixed-line subscriptions in Ireland increased by 17.12 per 100 people between 2004 and 2008. This was a larger cumulative increase per people than in either the EU15 or the OECD over the same time period. There was a slowdown in the adoption of fixed-line broadband in Ireland in 2008 which is coincident with the collapse in employment and economic output associated with the property and banking crisis that began in that year. Figure 3.2 tracks the diffusion process in Ireland and the OECD over time. The trend line shown for Ireland in Figure 3.2 starts two years later than the trend line representing the OECD. The line representing broadband penetration in the OECD begins in the second quarter of 2002 while the line representing broadband penetration in Ireland begins in the second quarter of 2004. Each time period in Figure 3.2 represents six months of elapsed time and the trend lines show the increases in the rate of penetration over the 13 subsequent six month time periods. Therefore the fourteen time periods (1-14) for Ireland encompass the second quarter of 2004 through to the fourth quarter of 2010, while the fourteen time periods for the OECD encompass the period spanning through to the second quarter of 2002 to the fourth quarter of 2008. By the end of the fourteenth time periods the cumulative increase in penetration for Ireland and for the OECD are found to be almost identical. Thus once we adjust for Ireland's two year delay in starting the broadband diffusion process relative to most other OECD countries we find that the diffusion path for fixed-line broadband penetration in Ireland is almost identical to that of the OECD. In this context, Ireland's continued 'lagging' of the OECD may simply reflect Ireland's later starting date for initial broadband take-off.

Figure 3.2: Broadband diffusion in Ireland and the OECD adjusted for Ireland's 'delayed' take-off



Note: The vertical axis represents broadband subscriptions per 100 people while the horizontal axis represents elapsed time with each time period representing six months. The fourteen time periods for Ireland signify Q2 2004 to Q4 2010 while the fourteen time periods for the OECD signify Q2 2002 to Q4 2008

Source: OECD broadband statistics 2011, Table 1G;

Although Ireland has maintained a low rate of fixed-line broadband penetration compared to the OECD, Ireland's wireless broadband subscription rates compare favourably to the

OECD. As shown in Table 3.6 Ireland had 47.1 wireless subscriptions per 100 inhabitants by the end of 2010 while the OECD averaged 41.6 and the EU15 averaged 43.4. Ireland had the sixth highest wireless subscription rate of the original EU15 countries by the end of 2010 and had the highest terrestrial fixed wireless (FWA) subscription rate in the same group. However, although nominally broadband, wireless broadband, and in particular mobile and satellite broadband, suffer from lower reliability and slower speeds than fixed-line broadband. Cave and Hatta (2009) argue that a four year gap still exists between fixed and mobile technologies in terms of speed and quality. While perhaps not of equal quality and therefore not true substitutes for fixed-line broadband, the relatively fast diffusion of wireless broadband platforms in Ireland may suggest a latent unfulfilled demand for affordable fixed-line broadband.

Table 3.6: Wireless broadband penetration in the OECD at December 2010

			Platform		
Rank	**Country**	**Total**	**Satellite**	**FWA**	**Mobile**
1	Korea	89.8	0.0	0.0	89.8
2	Finland	84.8	0.0	0.5	84.3
3	Sweden	82.9	0.0	0.0	82.9
4	Norway	79.9	0.0	0.7	79.2
5	Japan	76.7	0.0	0.0	76.7
6	Portugal	63.8	0.0	0.2	63.6
7	Denmark	62.9	0.0	0.9	62.0
8	Australia	56.2	0.5	0.1	55.6
9	United States	53.5	0.4	0.2	53.0
10	Poland	52.4	0.0	2.2	50.1
11	Luxembourg	50.4	0.0	0.0	50.4
12	Israel	49.0	0.0	0.0	48.9
13	**Ireland**	**47.1**	**0.1**	**1.7**	**45.3**
14	Switzerland	46.5	0.1	0.0	46.5
15	Iceland	46.3	0.0	0.7	45.6
16	New Zealand	39.5	0.3	0.6	38.6
17	Italy	38.7	0.0	0.0	38.6

Note: Table shows the number of wireless broadband subscriptions per 100 inhabitants measured by technology. December 2010. The OECD figure is the weighted average; Original data is supplied by national Governments. Table continues on the next page.

Source: OECD Broadband Statistics 2011, Table 1D (2);

Table 3.6 (continued): Wireless broadband penetration in the OECD at December 2010

			Platform		
Rank	**Country**	**Total**	**Satellite**	**FWA**	**Mobile**
18	Netherlands	38.0	0.0	0.0	38.0
19	UK	36.9	0.0	0.0	36.9
20	France	35.7	0.0	0.0	35.7
21	Slovenia	32.1	0.0	0.2	31.9
22	Slovak Rep.	31.2	0.0	3.4	27.9
23	Canada	30.4	0.0	1.0	29.4
24	Spain	27.8	0.0	0.0	27.8
25	Germany	26.0	0.1	0.0	25.9
26	Greece	24.6	0.0	0.0	24.6
27	Austria	20.8	0.0	0.3	20.4
28	Estonia	20.1	0.0	2.7	17.4
29	Czech Rep.	12.0	0.0	6.8	5.2
30	Belgium	10.2	0.0	0.2	10.0
31	Hungary	8.8	0.0	1.0	7.8
32	Chile	7.3	0.0	0.1	7.2
33	Turkey	2.0	0.0	0.0	2.0
34	Mexico	0.5	0.0	0.1	0.3
	OECD	41.6	0.1	0.3	41.3

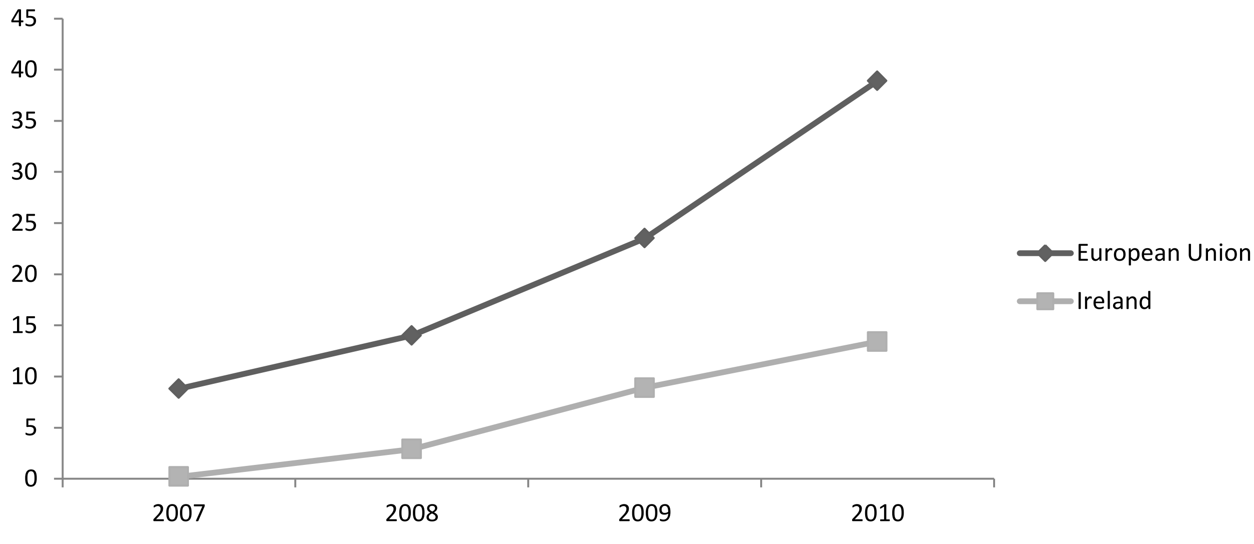
Note: Table shows the number of wireless broadband subscriptions per 100 inhabitants measured by technology. December 2010. The OECD figure is the weighted average; Original data is supplied by national Governments

Source: OECD Broadband Statistics 2011, Table 1D (2);

Measuring broadband quality: price and speed

Broadband in Ireland is of poor quality compared to OECD standards. Irish consumers experience lower than average speeds for higher than average prices. Forfás cites Teligen data for January 2011 which finds Ireland compares poorly with competitor countries when it comes to price. For example the fastest business package in Ireland at the time cost €706 per year before VAT, compared to €641 for Teligen's benchmarked group of thirteen European countries. The average business package offered in Ireland was the second slowest of the thirteen countries benchmarked despite being the fifth most expensive package offered in those countries (Forfás, 2011, p.23). Ireland's minimum monthly price including line charges for broadband in September 2010, when measured in terms of US$ Purchasing Power Parity (PPP), was $32.17, and this was the seventh most expensive rate in the OECD. The OECD average was $24.59 in terms of PPP. The minimum price per megabit per second (Mbit/s) in Ireland was also the seventh highest in the OECD at a price of 1.63 cents compared to an OECD average price of 1.21 cents. Recent reviews of Ireland's broadband performance by Forfás (2010 and 2011) found Ireland compares poorly to other Western European countries in terms of next generation high-speed infrastructure. For example, just 0.5 per cent of connections in Ireland were fibre-based at the end of 2010 compared to almost 10 per cent of connections in the OECD. The average advertised download speed in Ireland in September 2010 was 9,644Kbit/s, which ranks 32nd out of 34 OECD countries. The average advertised download speed in the OECD was four times faster than the average advertised download speed in Ireland (OECD, 2011). Just 13.4 per cent of fixed broadband lines in Ireland were faster than 10Mbps by the end of 2010, which compares to 38.9 per cent in the EU (see Figure 3.3).

Figure 3.3: Ireland has few high speed fibre lines



Note: The percentage of fixed broadband lines equal to or above 10Mbps – Ireland and the EU. Vertical axis represents the percentage of fixed broadband lines with speed equal to or above 10Mbps while the horizontal axis shows the year.

Source: European Commission Digital Agenda Scoreboard – based on average download speeds, see Forfás (2011, p.20, figure 5)

3.5 Explaining Ireland’s Broadband Market Development

Why do Ireland’s broadband indicators trail the OECD? In this section I consider a number of explanations for Ireland’s slow broadband development including low levels of investment in broadband infrastructure, lack of competition in the broadband market, and unfavourable demographic conditions. Ireland’s slow Internet market development was identified early in the international broadband take-off process. For example, Mauro Guillen and Sandra Suarez (2001) cite Ireland’s high cost of local calls, low PC ownership, low credit card penetration and a sales tax higher than in most other EU countries as obstacles inhibiting a faster increase in the use of the Internet in Ireland. Guillen and Saurez argue monopoly control of the local loop was inflating the cost of local calls and dampening consumer demand. World Stats (2011) and Point Topic (2011) argue that high wholesale costs, lack of competition, high retail prices and limited coverage adequately explain Ireland’s under-developed residential broadband market.

Lack of investment by the dominant market player

The extent of broadband coverage, the speed offered, and the quality of service available to consumers, will all be a function of the level of investment in broadband service provision. While the DSL market has natural monopoly characteristics, cable broadband technology makes the fixed-line broadband market a natural oligopoly rather than a natural monopoly. The dominant technology platform in almost every OECD country is DSL and in Ireland the infrastructure underlying DSL is controlled by the former state owned company Eircom which, according to the telecommunications regulator (Comreg, 2009), maintains significant market power. Until 1997 the state owned Telecom Éireann had an exclusive privilege giving it monopoly power over telephone services. Private companies in the telecommunications market were restricted to building networks on cables leased from Telecom Éireann (OECD, 2001b). In the 1990s the European Commission was requiring EU member states to fully liberalise their telecommunications markets, although Ireland obtained derogation in 1996 allowing Ireland to delay liberalisation until January 2000 (OECD, 2001b). In preparation for liberalisation, the Office of the Director of Telecommunications Regulation (ODTR) was created in June 1997, and the telecommunications market was fully liberalised in December 1998 (ODTR, 1999). Telecom Éireann was fully privatised in 1999 and its name changed to Eircom. Eircom’s telephone network infrastructure gave it significant market power in the market for Internet service provision. The company subsequently maintained its position as dominant market player in the broadband market. Eircom’s market share of all DSL lines in the second quarter of 2011 was 66.5 per cent (Comreg, 2011a, p.31). The level of investment in the monopoly network infrastructure is critically important to the development of the broadband market because of the large barriers to entry for competitors. Paul Sweeney (2004) and Donal Palcic and Eoin Reeves (2011) identify low levels of investment by Eircom in its broadband network. For example, Eircom's level of investment in its telecommunications infrastructure between 2002 and 2004 was insufficient even to offset the rate of depreciation in the network's capital stock. These low levels of investment in Eircom's network infrastructure may have contributed to the delayed take-off of broadband in Ireland compared to the EU15.

Eircom has undergone multiple changes of ownership since privatisation in 1999, and has experienced severe financial constraints since 2001. Eircom's ownership history since privatisation may partially explain the company's low levels of investment in its network infrastructure (Sweeney, 2004). Palcic and Reeves (2011) argue the low level of investment was a consequence of two Highly Leveraged Buy-Outs (HLBOs) which loaded the company down with large debt burdens and constrained its ability to invest in the network infrastructure. Leveraged buy-outs are company buy-outs financed by debt and the more leverage the higher the debt burden imposed on the company. According to William Melody (2008) the standard procedure of new owners following a successfully executed HLBO is to first delist the company from the stock exchange to reduce transparency. Next the new owners will usually attempt to generate short-term profit maximisation and dividend pay-outs by: (a) cutting operational expenses to a minimum, (b) selling off existing assets, (c) maximising debt financing, and (d) sacrificing investment in the long-term growth and development of the company. Palcic and Reeves (2011) recount Eircom's ownership history which I describe briefly here. The first HLBO occurred in December 2001 when the Valentia consortium of private equity investors purchased Eircom for €2.8 billion. Eircom's debt ratio rose significantly as a consequence of the HLBO with the company required to meet large annual payments merely to service its new debts. Valentia implemented a debt restructuring in 2003 to facilitate the payment of a €446 million dividend to shareholders. In total, between 2001 and 2003 the company's long-term debt rose from €599 million to €2.253 billion. Valentia refloated Eircom on the stock exchange in March 2004, and in August 2006 the company was the subject of a second HLBO, this time by Babcock and Brown Capital Limited. As a consequence of the second HLBO the level of Eircom's borrowings increased from €2.467 billion in 2006, to €4.268 billion by 2007. Singapore Technologies Temasek took over the company in early 2010. In March 2011 Eircom announced it was likely to default on its debts (Irish Times, 2011a) and had accumulated debts of €3.7 billion. By May 2011 Eircom had announced it was in danger of breaching its covenants within three or four months (Irish Times, 2011b) and by November 2011 the company was in negotiations with creditors to try and reschedule some of its debts and prevent a default and liquidation.

Eircom's on-going financial weakness from 2001 onwards will have constrained its capacity to invest in broadband network infrastructure and this lack of investment by the dominant market player may have inhibited Ireland's broadband market development. In particular, the underinvestment will have reduced the availability of broadband services, particularly in low population density areas, and will also have reduced the quality of broadband services where available. A lower quality service is likely to have reduced the level of consumer demand at any given price. Eircom's weak financial position also has negative implications for future levels of investment in next generation broadband infrastructure in Ireland.

Lack of competition

A market structure characterised by monopoly power will not produce an allocatively efficient outcome without the discipline imposed either by competitive pressures or by tightly enforced regulation. Ireland's broadband market structure may help explain why Ireland's broadband indicators trail those of the OECD. Lack of intra-platform competition in the DSL market compared to Europe has been identified as a reason for slow development (Forfás, 2010). Lisa Correa and Pietro Crocioni (2011) applied a hedonic price model to data from 2007 and found that Eircom had at least some degree of market power in the broadband market in that year. The Irish telecommunications regulator Comreg has described the incumbent DSL operator Eircom as controlling significant market power in the Irish DSL market as well as in the Irish fibre market (Comreg, 2010, pp. 7-8). According to Comreg: "Eircom has significant market power in the market for Wholesale Physical Network Infrastructure Access" and with regard to the next generation market Comreg "expects...Eircom's position of significant market power will prevail" Eircom held 46.4 per cent of the fixed broadband market at the end of the second quarter of 2011 (Comreg, 2011b, p.38). Despite full liberalisation of the fixed telephone market in 1998 (ODTR, 1999) competition has been slow to develop in Ireland. Control over the monopoly network and in particular control of the last-mile (the local loop) has privileged Eircom with a dominant position in the DSL market despite the company's financial difficulties. Sweeney, (2004) and Palcic and Reeves, (2011) argue that privatising Ireland's telephone network infrastructure was a strategic mistake. Ireland appears to be a case of market failure. Eircom has itself been a commercial failure and has repeatedly come close to bankruptcy despite its market power.

In a bid to stimulate intra-platform competition the telecommunications regulator Comreg pursued a policy of requiring Eircom to open its network to other broadband service providers through Local Loop Unbundling (LLU) (Comreg, 2006). Unbundling (LLU) enables other operators to offer services directly to consumers without having to construct their own networks thereby increasing competition, reducing prices and stimulating demand. However, Comreg complained that a lack of enforcement powers frustrated its ability to promote competition (Arthur Cox, 2008, p.1). Comreg was unable to compel Eircom to provide competitors with affordable access to the ‘last mile’ of the network. The Irish Independent (2011) reports Eircom successfully resisted the unbundling process and subsequently became locked in a series of legal and regulatory battles with Comreg over LLU and a number of related issues. The Chairman of Comreg and an assistant secretary at the Department of Communications both claimed Eircom was actively resisting competition and advances in technology for its own benefit (Irish Independent, 2011). The dogged resistance of a private monopoly to competition, as well as resistance to advances in technology, is an entirely rational and predictable response from an incumbent monopolist. Increased competition and technological change are both threats to the market share of a dominant market player. Eircom’s resistance to competition should have been readily anticipated and the regulator given sufficient power from the beginning to compel market players to open their networks to competition if the regulator judged it to be appropriate. The Communications Regulation Act 2007 subsequently armed Comreg with a “plethora of new investigative tools and enforcement powers” (Arthur Cox, 2008, p.1) and the power to fully implement its regulatory decisions in Ireland.

The rate of LLU has been lower in Ireland than in any other EU15 country. According to the European Competitive Telecommunications Association (ECTA, 2011), by the third quarter of 2009 just 2.5 per cent of total broadband access lines in Ireland were unbundled local lines. The equivalent figure for the EU was 25.3 per cent of all broadband access lines unbundled. The proportion of the incumbent’s DSL lines unbundled in 2009 was just 5 per cent in Ireland compared to 66 per cent in the EU15 (ECTA, 2011). The high costs competitors had to pay to rent lines provide one explanation for the low level of LLU in Ireland. Comreg’s regulatory stance was criticised as too accommodating to Eircom by a number of commentators including the broadband lobby group Ireland Offline (2004).

According to Forfás (2010), the monthly rental cost for LLU in Ireland was the highest in the EU15 in 2009. ECTA (2011) data shows that unbundled lines contributed just 0.6 subscriptions per 100 inhabitants in September 2010 to Ireland's broadband penetration rate. This compared to an average of 5.5 subscriptions in the EU15. ComReg and Eircom negotiated a deal in 2010 which it was intended would see LLU prices fall towards the European average.

The importance of LLU is contested in the empirical literature. Sangwon Lee and Justin Brown (2008) performed regression analysis on data from a sample of all thirty OECD countries and estimate the level of LLU significantly influences fixed broadband diffusion. They argue countries should adopt tough LLU policy to foster broadband deployment. However, Scott Wallstein (2006) finds LLU levels have no significant effect on broadband penetration and Martha Garcia-Murillo (2005) finds a positive effect only in middle income countries and not in high income countries. Empirical results regarding the impact of LLU on investment are mixed. Wallstein (2006) finds that unbundling mandates and some types of price regulation can reduce incentives to invest in infrastructure, while Walter Distaso, Paolo Lupi and Fabio Manenti (2006) find evidence supporting non-negative effects on investment. There are a number of theoretical arguments against tough LLU policy and there are potential costs as well as benefits associated with a regulatory policy favouring LLU. Jerry Hausman (2002) argues that LLU regulation distorted competition in favour of cable operators in the United States by impeding incumbent DSL operators' network rollout. De Bijl (2011) argues that LLU may undermine the rationale for new entrants to invest in their own networks if the regulator sets too low a charge for access to the network's local loop. Too low a charge may also undermine the business case for investing in upgrades to the existing network. Thus LLU regulation, while potentially capable of stimulating intra platform competition, may also impede infrastructure rollout into marginally profitable geographic locations, and may reduce the network owner's rationale for rollout of next generation fibre networks in the future.

While light LLU regulation and high rental costs for LLU may explain weak competition in Ireland's DSL market, LLU policy cannot explain weak competition from cable broadband providers. In the majority of OECD countries cable broadband is the most important inter-platform fixed-line competition to DSL broadband. In Ireland the cable broadband network is controlled by UPC. UPC is owned by Amsterdam based Liberty Global. UPC held the second largest share of the fixed broadband market by subscription with 21.7 per cent at the end of the second quarter of 2011 (Comreg, 2011b, p. 39). According to OECD data (2011), Ireland's cable broadband penetration rate is 4.5 subscriptions per 100 inhabitants, which trails the weighted OECD average of 7.3 subscriptions (see Table 3.5). Lack of strong inter-platform competition from the rival cable network may have stunted overall market development. Although evidence regarding the impact of inter-platform competition on broadband penetration is mixed, overall the evidence suggests that platform-based competition is an important factor explaining differences in broadband deployment (Garcia-Murillo, 2005; Distaso, Lupi and Manenti, 2005; Cava-Ferrereula and Alabau-Munoa, 2006; Wallstein, 2006; and Boyle, Howell and Zhang, 2008). While many studies find a correlation between technological competition and broadband penetration, Lee and Brown (2008) were unable to conclude that inter-platform competition has a statistically significant effect on broadband penetration in OECD countries. Are there underlying reasons why Ireland might inherently be a commercially unattractive location for investment and for competition from new entrants?

Demographic conditions

Population characteristics such as size, density, urbanisation and dispersion influence the development of fixed-line broadband infrastructure (DSL, cable and fibre) because they affect the per capita cost of infrastructure provision. Small and low density populations offer low revenues and high per capita costs for service provision. George Ford (2011) argues that relative broadband adoption rankings across the OECD are converging to the mature wire-line telephone adoption rankings in the mid-1990s. He suggests adoption of communication services is largely an economic and demographic issue rather than a policy issue. Compared to OECD country averages, Ireland has a small population, a low population density and a highly dispersed population (OECD, 2009a). Ireland's demographic characteristics make it a high-cost and low revenue market and undermine the economic case for entering the broadband market and for investing in broadband service provision. Faulhaber and Hogendorn's (2001) model of broadband market structure suggests that below a certain population density the broadband market will be a natural monopoly. According to their model, as density per square kilometre increases, so too will the probable number of firms in the market. On average more densely populated areas will have greater competition than sparsely populated areas. Greater competition has implications for broadband coverage and for price. Ireland's population density of 62 persons per square kilometre is far below the OECD average of 109 persons per square kilometre (United Nations, 2006 and CIA World Factbook, 2008). Ireland's low density weakens the commercial case for potential competitors to enter the fixed-line broadband market and Ireland’s market structure is therefore more likely to exhibit monopoly characteristics with higher prices and lower quality services

High density Korea and Japan are by far the most successful countries in developing next generation optical fibre networks and fibre is now the dominant platform in both countries (OECD, 2011, Table 1D 1). Large, highly urbanised and dense populations greatly improve the economics of installing fibre networks and this may explain the success of fibre in both countries. Preston, Cawley and Metykova (2007) surveyed broadband penetration in the EU15 and found penetration to be lower in rural communities than in urban centres, and also to be lower in countries with large rural populations. The Eircom chief executive made precisely this case in response to criticism of the weakness of Ireland’s broadband market (Sweeney, 2004). He argued that Ireland was an inherently low-revenue and high cost environment and recommended that government should stimulate demand with subsidies to users of the access network. Forfás (2010) also argue that urbanisation and population density are crucial factors determining the economic case for investing in broadband infrastructure. Ireland’s particular characteristics in this regard will remain a barrier to the provision of broadband access, particularly in rural areas. The dispersed and relatively rural nature of the Irish population may also have reduced the observability and demonstration effects of broadband (see Rogers, 1995) and therefore inhibited broadband diffusion.

Nevertheless, the European countries with the greatest success at achieving high rates of broadband penetration include the low population density countries of Norway, Iceland and Sweden (OECD, 2011, Table 1D 1). Therefore there must be other reasons underlying international differences in broadband penetration. For example, is Ireland’s higher than average household size contributing to a lower penetration rate, and therefore making the situation in Ireland appear worse than it really is? Other possible explanations for international differences include differences in broadband policy, differences in consumer ‘preference’ for broadband services and differences in the personal characteristics of potential broadband adopters.

3.6 Conclusion

The same economic, geographic and demographic factors inhibiting broadband market development may also inhibit the diffusion of next generation broadband in the future. Lack of access to high-speed fibre broadband is likely to be an issue of concern in Ireland over the next few years. The Telecommunications and Internet Federation estimates the cost of a fibre network for Ireland to be €2.5 billion (TIF, 2010) while Forfás (2011) estimates that the cost of fibre deployment to the premises in all towns with a population greater than 1,500 is €2.23 billion. Eircom’s severe financial difficulties make it unlikely the company will be able to raise sufficient funding for the construction of such a network. The Irish Government’s own public finance difficulties became so extreme in the aftermath of the 2008 economic crash that it was forced to seek outside financial assistance from the troika of the IMF the EU and the ECB, with the State entering a programme of financial support in November 2010 (Department of Finance, 2011). In this context, it is somewhat unrealistic for the State to consider constructing its own next generation network. Collaboration between Government, Eircom and other operators through Public-Private Partnerships (PPPs) is one alternative. Another option is for the infrastructure assets of existing commercial State Owned Enterprises (SOEs) to be bundled together and to then allow other operators access to the resulting network. The Programme for Government set out by the incoming government in 2011 proposed setting up a state holding company called NewEra to co-invest with the private sector and SOEs to “...provide next generation broadband to every home and business in the State” (Department of Taoiseach, 2011, page 14). The stated goal is to deliver fibre to the home or kerb for 90 per cent of homes and businesses with the remaining 10 per cent provided with high speed mobile or satellite broadband. Ireland’s apparent underperformance justifies a particular focus on Ireland as a case study. But is Ireland actually underperforming? In the next chapter I investigate this question empirically.

Chapter Four: Broadband Performance and the Role of Country Endowments

4.1 Introduction

In chapter three we discussed the current broadband policy debate and the development of Ireland’s broadband market. Successful technology diffusions have generally tended to be a path dependent phenomenon. Within the majority of OECD countries broadband penetration has followed the classic S-shaped diffusion path (OECD, 2011). Ireland’s raw subscription rate when measured on a per capita basis has been lower than that for the OECD throughout the broadband era. But does this actually mean Ireland is underperforming in terms of broadband diffusion? The rate of diffusion and the level of performance are not the same thing. In this chapter I consider international variation in broadband subscription rates and investigate the claim that Ireland is somehow ‘underperforming’. The broadband literature suggests a number of reasons for why Ireland might trail the OECD. Filippo Belloc, Antonio Nicita and Maria Rossi (2011) emphasise the importance for successful broadband market development of broadband policy including market interventions. Unfavourable geographic, demographic and economic conditions have also been proposed as barriers to market development (Faulhaber and Hogendorn, 2001), while inadequate competition, (Guillen and Saurez, 2001), and lack of investment (Palcic and Reeves, 2011) have been identified in the Irish case.

The focus of the chapter is on non-policy related explanations for Ireland’s lagging of the OECD. In particular, I consider a set of geographic, demographic, economic and vintage infrastructure, ‘country endowments’ which are each expected to provide differential advantages and disadvantages to countries, and which may therefore help explain international variation in broadband subscription. I make two main contributions in this chapter. The first contribution is to estimate the various effects of these country endowments on broadband penetration rates using standard Ordinary Least Squares (OLS) regression techniques. The second contribution is to then utilise these regression estimates in order to derive a broadband efficiency score for each OECD country. The results suggest that path dependency matters, with early adopting countries tending to maintain their advantage over time. Demographic conditions are also found to be important with higher population density leading to higher broadband penetration. There is some evidence that countries with geographically concentrated populations are more likely to have higher penetration rates, though this particular finding is non-robust. Higher penetration rates for pre broadband telecommunication technologies and higher rates of third level education per capita are both associated with higher broadband penetration rates. Even after adjusting for the cumulative effects of the non-policy country endowments the overall results show that Ireland performs below expectations. This suggests that Ireland is indeed underperforming.

The core empirical strategy draws upon methods for ranking broadband performance and efficiency that were originally devised for that purpose by George Ford, Thomas Koutsky and Lawrence Spiwak (2007 and 2008). Ford, Koutsky and Spiwak (FKS) argue that the level of broadband diffusion should not be confused with broadband performance. Their point is that broadband performance depends on a multitude of non-policy related factors and that therefore the 'raw' per capita subscription rates can be misleading as a guide to good broadband performance, and by extension misleading as a guide to best practice broadband policy. Following this argument, the cumulative impacts on broadband subscription of a set of non-policy related country endowments are estimated using OLS regression techniques. The goal is to disentangle the non-policy related impacts on broadband subscription from other impacts and in so doing construct a potentially more meaningful league table of international broadband performance. I measure each country's broadband efficiency by using the beta coefficients from the estimated model to compare the actual and the expected penetration rates for each country. Ireland is found to rank twenty second out of thirty countries in terms of broadband efficiency. My conclusion is that Ireland's low rate of penetration relative to the OECD is at least partially attributable to reasons beyond those identified and investigated in this chapter. The data used for the study comes from a variety of different sources. I use OECD data for broadband penetration (OECD, 2008a) as well as for third level educational attainment, for population dispersion, and for urbanisation (OECD, 2008c). World Bank data (2009) is used for fixed telephone mainline and Internet diffusion in 2000, while IMF data (2008) is used for income per capita. The study uses United Nations (2006) data for total population and for the population's age composition, and CIA data (2008) for land area. Data for average household size comes from the national statistical agencies while the data for the international PISA scores (representing educational aptitude) is taken from the NCES (2007).

The results suggest each year of delay before the start of a country's diffusion process cuts over 3.5 percentage points from future subscription rates. Ireland had a comparatively late start for broadband take-off relative to the OECD. The model estimates suggest that Ireland's delayed diffusion process is an important explanatory reason for the difference between Ireland and the OECD in subsequent years. One implication is that events predating the start of the Irish broadband take-off process in 2004 may be responsible for Ireland's slow market development. The models explain over 80 per cent of the international variation in broadband penetration and the results highlight the importance of demography, vintage infrastructure, education and path dependency for the diffusion of broadband. However, Ireland's low efficiency score indicates that other reasons are at least partially responsible for Ireland trailing the OECD average. These reasons may include differences in broadband policy including regulatory policy, differences in broadband market structure, differences in competition, differences in investment levels, and/or differences in the characteristics of potential broadband subscribers.

4.2 Broadband Diffusion and Non-policy Country Endowments

In this chapter I consider the wide variation in broadband diffusion within the OECD and investigate whether Ireland is in some way underperforming relative to expectations. Broadband's potential importance for long-run economic growth and development was discussed in chapter two. International broadband data shows that rates of diffusion have varied widely at the international level (OECD, 2008a; World Bank, 2009; ECTA, 2009). There are a number of regularly compiled scoreboards and rankings of international broadband market development. For example there are rankings compiled by the European Commission (2011), by the Organisation for Economic Co-operation and Development (OECD, 2011) and by the European Competitive Telecommunications Association (ECTA, 2011). The four main indicators of broadband market development that are regularly used in these scoreboards are: (a) the penetration rate - measured as the number of active subscriptions per 100 people); (b) the coverage rate – measured as the proportion of the population with the option to purchase affordable broadband; (c) the price for broadband services - measured as the monetary cost per unit speed of download and upload, and, (d) the speed of broadband services - measured as either the fastest, or the median, download speeds offered by the largest DSL and cable providers. In chapter three we described how Ireland consistently ranks in the bottom half of OECD countries for every one of the major broadband market indicators. Ireland's trailing of the OECD may suggest Ireland is in some way 'underperforming' and concern about broadband market failure has led to government intervention to stimulate the Irish broadband market (Forfás, 2011; Palcic and Reeves, 2011; DCENR, 2012b). But is Ireland actually underperforming? If so what is it underperforming at, and what does it even mean to be underperforming? In this chapter I consider the question of underperformance, in particular with regard to the broadband penetration rate. A technology's diffusion and pervasiveness within the economy determines the extent of the technology's overall economic impact. This makes the penetration rate of particular interest because the penetration rate measures the extent of broadband uptake in the population this makes it a good proxy for the level of broadband diffusion.

Table 4.1: Broadband penetration in the OECD ordered by 2008 ranking

Rank	Country	2008	2004	Rank	Country	2008	2004
1	Denmark	36.72	16.90	16	Australia	23.54	5.19
2	Netherlands	35.53	15.43	17	Japan	22.97	12.67
3	Norway	33.36	11.26	18	Austria	20.58	8.65
4	Switzerland	32.70	14.55	19	New Zealand	20.39	3.48
5	Iceland	32.32	15.19	20	Spain	19.83	6.46
6	Sweden	32.30	12.34	21	Ireland	19.11	1.61
7	South Korea	31.18	24.18	22	Italy	18.22	6.02
8	Finland	30.69	10.93	23	Czech Republic	15.79	0.75
9	Luxembourg	28.29	5.57	24	Hungary	15.72	2.52
10	Canada	27.89	16.39	25	Portugal	14.82	6.27
11	United Kingdom	27.61	7.36	26	Greece	11.20	0.23
12	Belgium	26.45	14.18	27	Slovak Republic	9.80	0.62
13	France	26.43	7.87	28	Poland	9.57	1.19
14	Germany	26.25	6.56	29	Turkey	6.79	0.29
15	United States	25.02	10.86	30	Mexico	4.71	0.74

Note: Number of subscriptions per 100 inhabitants

Source: OECD (2009b) Broadband Portal, online, Table 1D (1)

The penetration rate is measured as the number of broadband subscriptions per 100 people. Table 4.1 shows the penetration rate as it was for the then thirty members of the OECD in 2004 and in 2008. Technology diffusion is a path dependent phenomenon and penetration rates for successful technologies tend to increase over time. There were zero instances of the penetration rate declining in an OECD country over any of the twelve month periods between 2004 and 2008. The empirical (Griliches, 1957; Mansfield, 1963) and theoretical (Geroski, 2000; Stoneman, 2001) technology diffusion literatures both emphasise that successful technologies exhibit a path dependent S-shaped diffusion curve. The changing penetration rates between 2004 and 2008 paint a picture of a successful technology passing through the pre-maturity high growth stage of the S-shaped diffusion process. The penetration rate increased over the period for every OECD country and more than doubled in twenty six of the thirty countries. Luxembourg and Norway had the largest percentage point increases in broadband penetration over the period while Mexico and Turkey had the smallest percentage point increases. Ireland’s percentage point increase was the twelfth largest of the thirty countries (see Table 4.2). In some cases there were major changes in a country’s overall ranking over the period. For example, South Korea had the highest broadband penetration rate in 2004, but had the third lowest percentage point increase between 2004 and 2008, and as a consequence by 2008 had been overtaken by six other countries. The six highest penetration rates in 2008 all belonged to small and high income Western European countries. Denmark led the OECD in 2008 with 36.7 subscriptions per 100 inhabitants. This was followed by the Netherlands in second place with 35.5 subscriptions, and then by Norway in third place with 33.4 subscriptions. Ireland’s penetration rate of 19.1 subscriptions was ranked twenty first out of thirty countries in 2008. This was an improvement of three places on Ireland’s 2004 ranking. Ireland’s low ranking appears to suggest underperformance. However, diffusion is not the same as performance because diffusion is dependent on a wide range of factors, many of which are beyond the control of policymakers. It is possible that non-policy related factors are responsible for Ireland’s comparatively weak broadband market development and that Ireland is well performing once the cumulative impacts of these factors are accounted for.

Table 4.2: Broadband penetration in the OECD ordered by change between 2004 and 2008

Rank	Country	Change	Rank	Country	Change
1	Luxembourg	22.72	16	Spain	13.37
2	Norway	22.10	17	Hungary	13.20
3	United Kingdom	20.25	18	Belgium	12.27
4	Netherlands	20.10	19	Italy	12.20
5	Sweden	19.96	20	Austria	11.93
6	Denmark	19.82	21	Canada	11.50
7	Finland	19.76	22	Greece	10.97
8	Germany	19.67	23	Japan	10.30
9	France	18.56	24	Czech Republic	10.04
10	Australia	18.35	25	Slovak Republic	9.18
11	Switzerland	18.15	26	Portugal	8.55
12	**Ireland**	**17.50**	27	Poland	8.37
13	Iceland	17.13	28	South Korea	7.00
14	New Zealand	16.91	29	Turkey	6.50
15	United States	14.16	30	Mexico	3.97

Note: Change in number of subscriptions per 100 inhabitants

Source: OECD (2009b) Broadband Portal, online, Table 1D (1) and author’s calculations.

The FKS models of broadband efficiency

If raw diffusion data is not the same as broadband performance and efficiency then how can we assess broadband performance? Performance is a relative concept and Ford, Koutsky and Spiwak (2007 and 2008) have developed a set of indices to rank the relative broadband performance of a group of countries. They argue:

> ...the significant differences across OECD countries are not limited to population, citing to raw data – without further analysis – provides a misleading picture of broadband adoption and provides a poor basis upon which responsible public policy can be based (Ford, Koutsky and Spiwak, 2008, p.3).

The Ford, Koutsky and Spiwak models, henceforth the FKS models, control for the cumulative effects of a set of country characteristics on broadband market indicators. They collectively term these characteristics ‘national endowment sets’. These endowments are a collection of geographic, demographic, historical, and economic characteristics which are expected to influence broadband diffusion, yet which are exogenous to, or independent of, national broadband policy. The endowments can be seen as differential advantages and disadvantages which are unrelated to broadband era policy. As Ford, Koutsky and Spiwak put it:

> A more relevant comparison of broadband success takes into account a wide range of economic and demographic endowments, looking not to raw subscriptions as an efficiency measure but rather at a failure to perform up to expectations...a country with low GDP can be a more ‘efficient’ adopter of broadband than a rich country even if its raw subscription rate is lower (Ford, Koutsky and Spiwak, 2008, p.3).

The FKS indices are called the Broadband Performance Index (BPI) and the Broadband Efficiency Index (BEI). The two indices are calculated by comparing actual penetration rates with the Expected Penetration Rate (henceforth EPR) for each country. The EPR for each country is generated by first estimating an econometric model of broadband penetration and then plugging the particular values for the individual country’s endowment set into the estimated model. Countries with a broadband penetration rate greater than the country’s EPR will rank highly in the performance and efficiency indices. The ratio of the actual penetration rate to the EPR is taken as the measure of the efficiency with which a country is transforming its non-policy endowments into broadband penetration outputs.

The non-policy country endowments

International variation in broadband penetration has been extensively discussed in the literature. For example, see Charles Ferguson (2002 and 2004) and Martin Fransman (2006) for overviews of different country experiences. A number of proposed reasons for differences in international outcomes have been suggested. Competition is often identified as a reason. As described in chapter three, the provision of fixed-line broadband infrastructure has natural monopoly characteristics. Fixed-line broadband service provision is subject to increasing returns to scale and declining average costs. This is due to the combination of high fixed costs associated with network construction, for example the laying of cables and the construction of telecommunications exchanges, and the low marginal costs associated with supplying customers with additional bits of high frequency data (Faulhaber and Hogendorn, 2001). High fixed costs are a barrier to firms wishing to enter the market to supply fixed-wire broadband, particularly where there is already a dominant incumbent with a network infrastructure already in place. Competition provides consumers with greater choice; it forces companies to improve service quality, and it will exert downward pressure on prices (Atkinson, 2007b). Competition also has implications for broadband coverage and for price. Lower prices and greater coverage are likely to increase broadband penetration by stimulating demand. Richard Cadman and Chris Dineen (2006) estimate that a 1 per cent reduction in the Herfindahl-Hirschman (HH) index for the broadband market will lead to a

1.66 per cent increase in a country's broadband penetration rate. A reduction in the broadband market's HH index represents a reduction in the degree of industry concentration in the market. Marcelo Grosso (2006) also finds that competition has a statistically significant and positive effect on broadband penetration. So what non-policy country endowments are likely to influence the level of competition and investment in the broadband market?

Countries and regions with large populations of potential customers will be more commercially attractive to broadband service providers. The actual number of market entrants is expected to be a function of potential market size. Where the total customer base within a region does not reach a certain minimum threshold, it is possible no new firms at all will decide to enter the market. We can expect the average supply cost per subscription in a particular geographic area to be highly sensitive to the population density of the location. Higher population densities are more attractive to broadband service providers because there are lower per capita costs for service provision. Serving people physically spread further apart will not just require more cabling but will also require more electronic components to enhance signal strength. Gerald Faulhaber and Christiaan Hogendorn (2001) show that the structure of the broadband market will be a function of the region's population density. The model also shows that below a certain population density the market will be a monopoly. Multiple networks bring additional costs and it does not make commercial sense to construct a second network unless there is an expectation of a sufficiently large rate of return. The expected number of firms in the market will increase as the population density increases. Competition is therefore likely to be regionally asymmetric, with densely populated areas having a greater choice of provider than sparsely populated areas. Higher per capita costs and less intense competition will lead to higher prices and poorer quality service. This increase in price and reduction in quality will reduce the per capita level of broadband demand in low density areas. On the other hand the higher rate of return on investment in high density areas will encourage greater competition, potentially reducing prices, improving quality, and thereby further fuelling per capita broadband demand. In this way urban and rural penetration rates can diverge over time. This is the phenomenon of the digital divide. Tony Grubesic (2002) has found that Internet activity is higher in geographic locations with higher population density. Kenneth Flamm (2005) finds that geophysical variables are important determinants of differences in broadband deployment across regions and he argues that omitting geophysical variables will result in significant estimation biases. However, Flamm finds that it is absolute market size rather than population density which determines broadband penetration. Kenneth Flamm and Anindya Chaudhuri (2007) estimate that urban areas will have higher penetration rates than rural areas while Paschal Preston, Anthony Cawley and Monika Metykova (2007) find that penetration is lower in rural communities than in urban centres and is also lower in countries with large rural populations. Countries and regions with geographically concentrated populations are likely to be more attractive markets for potential suppliers than countries or regions with more dispersed populations. Barriers to market entry are lower where the population is geographically concentrated or heavily urbanised. An important reason is that service providers can target their resources specifically at the high density locations where the commercial case for service provision will be higher. On the other hand, opportunities for targeted market entry will be more difficult where the population is highly dispersed across the region. As we discussed in chapter three, the broadband infrastructure underlying the main Digital Subscriber Line (DSL) technology utilises the same copper wire network infrastructure as the traditional telephone system. This means that countries and regions with highly developed fixed line telephone network infrastructures in place prior to the start of the broadband era will require lower investment upgrades to provide DSL broadband services.

The broadband penetration rate is also likely to be influenced by certain socio-economic and household characteristics. A larger average household size is likely to translate into lower ‘raw’ subscription rates per capita because most households are likely to require just a single active connection irrespective of the number of persons actually living in the household (Ford, 2011). While a single person household may have a preference for one subscription, it is unlikely that a seven person household will have a preference for seven subscriptions, or even more than just a single subscription. Higher levels of education are likely to be associated with a greater propensity for computer and Internet use. Francesco Caselli and Wilbur Coleman (2001) and Hyunbae Chun (2003) report that educational attainment has a statistically significant effect on broadband adoption decisions. Better educated populations may have greater familiarity, exposure to, and ability to use, new technologies. Education may also inculcate a greater willingness to try new technologies, and populations with high ratios of third level graduates may have a greater preference for technology in general and for broadband in particular. Digital literacy and comfort with technology will influence preferences for ICT adoption. Jan Youtie, Philip Shapira and Greg Laudeman (2007) find that lack of digital literacy is a large barrier to broadband adoption. Pre-existing users of narrowband Internet access technologies are likely to be more familiar with the potential benefits offered by Internet applications than non-users, and are therefore more likely to subscribe to broadband. Grosso (2006) finds that learning effects associated with education, including demonstration effects, are positively related to broadband penetration while Paul Rappaport, Donald Kridel and Lester Taylor (2002) find that education is a strong predictor of broadband adoption. The age profile of the population may also influence broadband adoption rates to the extent that older consumers have lower levels of digital literacy and comfort with technology as well as reduced preference for Internet services (O'Donnell, McQuillan and Malina, 2003; Howick and Whalley, 2008).

Finally, broadband access is to some extent a luxury good. Populations with higher per capita income will have greater ability to pay and this should result in higher levels of per capita consumption. Wealthier populations will also have a higher level of demand for broadband at a given price. The higher level of demand strengthens the commercial case for providing broadband services in wealthier locations and encourages investment in broadband infrastructure in high income countries. The implication is there may be greater competition and investment in the provision of broadband services in richer areas, regions and countries. If this is so, then the quality of the service offered may gradually improve in wealthier regions at the expense of less affluent regions. Rappaport, Kridel and Taylor (2002) find that income is a strong predictor of purchases of broadband services. Austan Goolsbee (2002) and Hal Varian (2002) separately estimate income effects and find that the demand for broadband services is very income elastic. Flamm (2005) finds income and wealth to be important determinants of penetration while Grosso (2006) finds that higher GDP per capita is positively related to broadband penetration. What are the implications of these findings for our expectations and how can we estimate the cumulative impacts of non-policy related country endowments on broadband penetration?

4.3 Strategy for Estimating Broadband Efficiency: A Ford, Koutsky, Spiwak Approach

Basic model of broadband penetration

In the natural sciences theories are usually tested through experimentation. Experiments are based on the gathering and interpretation of observable and measureable data. Richard Dawkins (2009) argues that successfully conducted experiments require something to be manipulated or changed in a systematic way, while James Heckman (2008) argues that experimental manipulation is the only way to be sure an observed correlation has any causal significance. Pre-existing theories and evidence helps inform plausible hypotheses, and can help guide our expectations regarding the direction and size of causal effects. Our theories and the available data then inform an appropriate methodology for testing these hypotheses through empirical estimation. Economics can assist us in formulating and testing theories about socio-economic phenomena. For example, certain core economic principles, such as the importance of incentives in determining producer and consumer behaviour, can help us frame an analysis of broadband outcomes and inform our choice of predictor variables. Virtually the entire field of econometrics is dedicated in one form or another to establishing causality with regard to socio-economic phenomena (Hicks, 1979). However, unlike in the natural sciences, deliberate experiments relevant to socio-economic issues are rarely feasible in practice. How can we overcome this limitation?

Econometrics is structured around principles of inquiry. These principles include the scientific idea of the experiment and the desire to replicate or ‘mimic’ natural experiments with a view to establishing causation (Granger, 1990). Trygve Haavelmo (1944) argues that fluctuations in outcomes will have many sources. Yet just because an event took place does not imply that everything preceding it ‘caused’ that event. We can use economic modelling and econometric principles to formulate, estimate and test the relationships between economic variables. At its heart, the whole purpose of this modelling exercise is to establish causation and to help us enhance and refine our understanding (Angrist and Pischke, 2009). In other words, economic modelling can help us to pose and answer socio-economic questions. The usefulness of an economic model is largely a function of its ability to explain and predict economic outcomes. While a comprehensive explanation of a socio-economic phenomenon may involve thousands of factors, the model’s actual usefulness to policymakers is a function of its simplicity or ‘parsimony’. Some channels of influence on the outcome are not important, or at least are not as important as other channels of influence. Overcomplicated economic models can miss or hide important statistical relationships or insights that are central to good policies.

In this chapter I construct an empirical model to estimate the cumulative effects on broadband diffusion of a set of national country endowments. According to Griliches, (1957); Mansfield, (1963) and Stoneman, (2001), the patterns of diffusion for successful technologies tend to exhibit a path dependent S-shaped curve with total diffusion increasing over time. Thus, if we assume broadband diffusion follows the historical trend for successful technologies, then there is likely to be a positive relationship between the numbers of years since broadband began diffusing in a country and that country’s penetration rate at a given time. It is therefore important to include a time elapse or ‘year’ variable in the basic model.

Doing so allows us to control for the characteristic path dependency of technology diffusion and also helps us to capture the impact of delays in the start of the diffusion process.

The dependent variable of interest in the model is the broadband penetration rate. The penetration rate is measured as the number of active fixed broadband subscriptions per one hundred people. The empirical model is generated using Ordinary Least Squares (OLS) multiple regression techniques. There are thirteen independent variables in the basic model. One of these variables measures the number of years elapsed since the baseline broadband take-off year of 2002, while the twelve remaining independent variables are a set of national country endowments. All of the endowment variables are assumed to be unrelated to national broadband policies. The collection of national endowments for each country is henceforth described as the ‘endowment set’ for that country. The particular group of variables included in the endowment set were chosen for a number of reasons. First, each variable is expected to influence international patterns of broadband subscription by providing differential advantages or disadvantages for the various countries in the dataset, second, each variable chosen is objectively quantifiable, and third, each variable is likely to have been exogenous to the broadband policies of the 2002 to 2008 period. The variables in the endowment set contain information about the geographic, demographic, socio-economic, and vintage technology characteristics of the then thirty OECD countries. The disturbance term ε_i shown in Equation 4.1 reflects all of the impacts on the broadband penetration rate that are not captured by the model as well as a random effect.

The basic empirical model is expressed as

$$\text{SubRate}_i = \quad f(\beta_0 + \beta_1 \text{Year}_i + \beta_n (\text{Endowment Set})_i + \varepsilon_i) \qquad (4.1)$$

Where

SubRate_i is the raw subscription rate for country *i* and is considered a proxy for broadband penetration

ε_i is the disturbance term specific to country *i*.

$(\text{Endowment Set})_i$ is the set of national endowments specific to country *i*.

Findings of statistical significance can help reveal underlying causal relationships between the broadband penetration rate and the different country endowments. However, Stephen

Ziliak and Deirdre McCloskey (2008) argue that, what they describe as an overemphasis on statistical significance in the social sciences - which they call the ‘cult of statistical significance’ - leads to an overshadowing of the importance of coefficient size. As they put it: “statistical significance...is on its own almost valueless, a meaningless parlour game” (Ziliak and McCloskey, 2008, p. 2). Their point is that we need to look beyond mere statistical significance and consider the relative importance of the predictor variables. The beta coefficient represents the size of the effect of the predictor variable on the dependent variable. Where the beta coefficient is small it means that the causal impact is relatively unimportant and where the beta coefficient is large it means the opposite. Having obtained the beta coefficients for each of the statistically significant predictor variables I then use these coefficients to estimate a broadband efficiency score for each country.

Measuring broadband efficiency

In the second part of the empirical exercise I use the derived model of broadband penetration to determine whether Ireland’s relatively low broadband penetration can be explained as a consequence of a relatively weak set of country endowments. Specifically, and drawing on a methodological approach developed by George Ford, Thomas Koutsky and Lawrence Spiwak (2007 and 2008), I estimate whether Ireland’s Actual Penetration Rate (APR) exceeds or falls below Ireland’s Expected Penetration Rate (EPR), given Ireland’s set of country endowments. If Ireland’s APR is greater than or equal to its EPR then I consider Ireland to be performing reasonably well and we can therefore attribute Ireland’s low broadband penetration to a weak set of country endowments. On the other hand if Ireland’s APR is less than its EPR I consider Ireland to be performing relatively poorly and in this case we can conclude that additional factors not incorporated in the empirical model are at least partially responsible for Ireland’s low penetration rate.

The Ford, Koutsky and Spiwak, or FKS models (2007 and 2008); econometrically generate a performance score for each OECD country. In the 2007 FKS model the performance score can take any value between -1 and +1 with a score of +1 representing an excellent performance. The 2007 FKS model takes into account a number of factors such as income, income inequality, education, the population age and the population density. However, the FKS model also includes price. Price is a function of regulatory policy. The results of the 2007 FKS model suggest that countries often cited as broadband miracles, such as Korea and Japan, are only average performers once the national country endowments are accounted for.

They also find that a country’s demographic and economic endowments explain the vast amount of the variation across the OECD. The 2008 FKS model uses maximum likelihood rather than least squares estimation and again includes price as a variable. On this occasion, Ford, Koutsky and Spiwak (2008) again find that country endowments explain almost all of the international variation in broadband subscription.

For the purposes of the current study I exclude all policy related variables and restrict the analysis to directly measurable variables. The geographic, demographic and socio-economic variables used in the study are all assumed to be independent of telecommunications policy, while I assume the pair of ‘vintage infrastructure’ variables to be independent of broadband policy. Differences in endowment sets will generate differential advantages and disadvantages for countries in terms of broadband market development. We can expect countries with highly beneficial sets of endowments to have higher penetration rates on average than countries with less beneficial sets of country endowments. For example, Sweden has an average household size of 2.1 and Mexico has an average household size of 4.2. All else being equal, we can expect that the differences in average household size will be reflected in a higher raw subscription rate per capita in Sweden than in Mexico. If Sweden does not have a higher raw subscription rate per capita then the suggestion is that Mexico has in some sense performed better or more efficiently than Sweden. To measure each country’s broadband efficiency score I first derive an Expected Penetration Rate (EPR) for each country. The EPR for each country is generated by plugging the values for the statistically significant country endowments into the best fitting model specification. Specifically, the EPR for each country is derived using the estimated beta coefficients of the set of statistically significant country endowments. I then compare the EPR for each country to the country’s Actual Penetration Rate (APR). The countries are then ranked based on the efficiency with which they are transforming their set of country endowment ‘inputs’ into broadband penetration ‘outputs’. The efficiency score for each country is calculated as follows:

$$\text{Broadband efficiency score} = (APR)_i/(EPR)_i \tag{4.2}$$

Where

APR_i = The actual broadband penetration rate obtained by country *i*

EPR_i = The expected broadband penetration rate given the endowment set of country *i*

The obtained efficiency scores are at best merely indicative of actual broadband market efficiency and performance. In particular, the efficiency score should not be taken as a direct measure of the quality of a country's broadband policy, as there are a number of other relevant factors beyond the scope of and not captured in the empirical model. For example, poor efficiency scores may reflect low levels of competition or investment, high levels of corruption, a weak regulatory regime, weak or inappropriate institutional design, cultural reasons, and even bad luck. Nevertheless, the overall efficacy of broadband policy will also be captured within the efficiency score. Therefore good policy is likely to be associated with higher efficiency scores and higher efficiency scores can be seen as a proxy for good policy.

Data sources

The period from 2002 onwards was the time when broadband access gradually came to be widely available in the population and when broadband penetration rates started to take-off within the majority of OECD countries. Ireland's fixed (wired) broadband penetration rate did not exceed one subscription per one hundred inhabitants until early 2004. Ireland was the last Western European country to pass this threshold, and by way of context, twenty one out of thirty OECD countries had already achieved this rate of penetration either before or by 2002 (OECD, 2011). I obtain seven years of data (2002-2008) for each of the thirty OECD countries as this represents the main broadband take-off period in the OECD. The data sources used in the study are shown in Table 4.3. The broadband diffusion process had not meaningfully begun for a substantial fraction of OECD countries prior to 2004. Six different OECD countries had less than one broadband subscription per 100 inhabitants in 2002 while three of these countries still had less than one broadband subscription per 100 inhabitants a year later in 2003.

The set of selected country endowments is described in Table 4.3. The set of endowments include a geophysical variable (the land area) and six demographic variables (the population size, the population density, the population concentration, the degree of 'urbanicity' or urbanisation of the population, the average household size, and the proportion of the population aged 60 or over). There are three socio-economic variables including the income per capita; the extent of third level qualifications in the 25 to 64 year old age cohort in 2004, and the educational competence of teenagers as measured by PISA scores. There are also two variables signifying the quality of the pre broadband telecommunications infrastructure. These are the number of telephone mainlines per one hundred people in 2000, and the number of Internet subscriptions per one hundred people in 2000. In addition to the country endowments I include a year variable in order to control for the path dependent nature of technology diffusion. Finally, the dependent variable is defined as the number of broadband subscriptions per one hundred people. The dependent variable is a proxy for broadband penetration. Decomposing the ‘endowment set’ variable from Equation 4.1 into its component parts provides the following expression:

$$\mathrm{SubRate}_i = f(\beta_0 + \beta_1\mathrm{Year}_i + \beta_2\mathrm{House}_i + \beta_3\mathrm{Size}_i + \beta_4\mathrm{Pop}_i + \beta_5\mathrm{Dens}_i + \beta_6\mathrm{Concen}_i + \beta_7\mathrm{Urban}_i + \beta_8\mathrm{Income}_i + \beta_9\mathrm{EdPisa}_i + \beta_{10}\mathrm{EdGrad}_i + \beta_{11}\mathrm{FixTel}_i + \beta_{12}\mathrm{IntSub}_i + \beta_{13}\mathrm{Age}_i + \varepsilon_i) \quad (4.3)$$

Where

$\mathrm{SubRate}_i$ is the subscription rate for country i and is a proxy for broadband penetration

ε_i is the disturbance term specific to country i

Table 4.3: Non-policy country endowments

Endowment Type	**Code**	**Definition**	**Data Source**
Geophysical			
	Size	Physical size of the country in square kilometres	CIA (2008, World Factbook, Country Tables)
Demographic			
	Pop	Total population	United Nations (2006, Annex: Table A. 2.)
	Dens	Population Density - Number of people per square kilometre	Population/Physical Size
	Concen	Degree to which the population is geographically concentrated	OECD (2008c, Factbook, Country Tables)
	Urban	Degree of urbanisation of the population	OECD (2008c, Factbook, Country Tables)
	House	Average household size by number of people	National Statistical Agencies
	Age	Proportion of the population aged 60 or over	United Nations (2006, Annex: Table A. 10.)
Socio-economic			
	Income	Country’s per capita income	IMF (2008, WEO, October)
	EdGrad	Proportion of the 25-to-64 age cohort with 3rd level qualifications in 2004	OECD (2008c, Factbook Country Tables)
	EdPisa	Country’s achieved Pisa scores	NCES (2007, p. 6, Table 2)
Vintage Infrastructure			
	FixTel	Number of telephone Mainlines per 100 people in 2000	World Bank (2009, ICT Country Tables)
	IntUse	Number of Internet Subs. per 100 people in 2000	World Bank (2009, ICT Country Tables)
Non-endowments			
	SubRate	Number of broadband subscriptions per 100 persons	OECD (2008a, Table 4.13)
	Year	Signifies the number of years that have passed since 2002	Na

Sources: United Nations (2006, http://www.un.org/esa/population/publications/wpp2006/WPP2006_Highlights_rev.pdf); NCES (2007, http://nces.ed.gov/pubs2008/2008016.pdf); CIA (2008, https://www.cia.gov/library/publications/the-world-factbook/print/textversion.html) IMF (2008, http://www.IMF.org/external/pubs/ft/weo/2008/02/weodata/weooct2008all.xls); OECD (2008a, http://www.oecd.org/document/0,3746,en_2649_201185_46462759_1_1_1_1,00.html); OECD (2008c, http://stats.oecd.org/BrandedView.aspx?oecd_bv_id=factbook-data-en&doi=data-00376-en); World Bank (2009, http://data.worldbank.org/data-catalog/ICT-table);

In order to ensure consistency across countries I use the OECD's (2006) definition of broadband. This definition only counts download speeds equal to or faster than 256kbits/s. The data for broadband subscription is obtained from the OECD's (2008a) broadband portal. The data for physical land size is measured in square kilometres and is obtained from the Central Intelligence Agency's World Factbook (2008). Population data and population age data are both derived from the United Nations World Population Prospects (2006) and are a mix of reported and interpolated data. Population density is then expressed as the total population divided by the land area in square kilometres. The data for geographic concentration and for urbanicity was obtained from the OECD Factbook (2008c). Geographic concentration is a measure of the degree to which the population is spatially concentrated within the country. Urbanicity is a measure of the degree to which the populated is located in urban areas. The OECD derives the urbanicity measure from the distribution of populations into urban, intermediate and rural regions. Average household sizes are obtained from national statistical agencies. As a proxy for the population's educational attainment I use the proportion of the population of 25-to-64 year olds with third level qualifications. This data was obtained from the OECD Factbook (2008c). To measure the educational aptitude of the younger population I use the Programme for International Student Assessment (PISA) results for science and mathematics literacy. These are known as the PISA scores and are obtained from the National Centre for Education Studies (NCES, 2007). The income per capita data is obtained from the IMF's World Economic Outlook (October, 2008). Finally, 2000 data for the number of fixed telephone mainlines per 100 people, and also for the number of Internet subscribers per 100 people, was obtained from the World Bank's online data resource (2009). I show the expected directions of influence on broadband penetration in Table 4.4.

Table 4.4: Expected direction of impact on broadband penetration

Geophysical	**Demographic**	**Socio-economic**	**Vintage infrastructure**
Land Area (-)	Total population (+)	Per capita Income (+)	Telephone mainlines (+)
	Population density (+)	Third level graduates (+)	Internet subscribers (+)
	Pop. concentration (+)	Aptitude: PISA score (+)	
	Population urbanicity (+)		
	Ave. household size (-)		
	Proportion aged 60+ (-)		

Note: A (-) sign means the expected direction of impact on broadband penetration is negative while a (+) sign means the expected direction of impact on broadband penetration is positive

4.4 Models of Broadband Efficiency

Descriptive statistics and correlations

The range of values obtained for each of the variables is shown in Table 4.5. There is large variation between countries both in terms of physical size and in terms of total population. Ireland's total population is well below the OECD median while Ireland also has a lower than average population density. Ireland's population is more dispersed and more rural than the OECD median, while Ireland also has a higher than average household size. Finally, Ireland had a substantially lower than average rate of Internet subscription in 2000. All these factors are expected to have disproportionately inhibited the diffusion process in Ireland relative to the OECD. On the other hand Ireland's small physical size, high income per capita, and small proportion of over 60s in the population are all expected to have facilitated the diffusion process. Ireland's values for both of the education variables and for the per capita number of telephone mainlines in 2000 are almost identical to the OECD median.

Table 4.5: Range of values for country endowments (2008 unless stated)

Variable	Code	Ireland	Median	Low	High
Broadband Subscription Rate	SubRate	19.11	24.28	4.71 Mexico	36.72 Denmark
Average Household Size	House	2.81	2.6	2.1 Germany/Sweden	4.2 Mexico
Land Size (in square kilometres)	Size	70,280	256,750	2,586 Luxembourg	9,985K Canada
Population ('000s)	Pop	4,374	10,907	303 Iceland	308,753 USA
Density (per square kilometre)	Dens	62.24	108.94	2.72 Australia	490.99 Korea
Geographic Concentration	Concen	29	38	12 Slovak Republic	82 Canada
Urbanicity	Urban	28	41.5	11 Czech Rep/Norway/Slovakia	85 Netherlands
Income (000's of US$ PPP)	Income	46.6	34.55	12.4 Turkey	79.4 Luxembourg
PISA Scores	EdPisa	508	506	410 Mexico	563 Finland
Third Level Graduates in 2004	EdGrad	24.8	24.9	9.1 Turkey	42.6 Canada
Telephone Mainlines in 2000	FixTel	50.22	50.56	14.55 Mexico	74.72 Switzerland
Internet Subscribers in 2000	IntUse	12.47	17.05	1.85 Turkey	37.75 Denmark
Aged 60 and over	Age	16.2	21.3	9.3 Turkey	27.8 Japan

Note: Third level graduates, telephone mainlines, and Internet subscribers are all per 100 persons.

The range of broadband penetration rates is quite wide even within the OECD club of rich nations. Subscription rates in 2008 varied from over 35 per 100 people in Denmark and the Netherlands to under 10 per 100 people in Poland, Slovakia, Mexico and Turkey (OECD, 2008a). In the same year Ireland had the 10th lowest subscription rate out of the 30 OECD countries. The co-efficient of variation for the broadband subscription rate declined each year from 2002 to 2008 (see Table 4.6). A declining co-efficient of variation indicates reduced dispersion and implies that for broadband penetration there is convergence over time between countries.

Table 4.6: International convergence in broadband penetration over time, 2002 to 2008

	Co-efficient of variation (Mean)	Co-efficient of variation (Median centred)
2002	1.25	2.412
2003	0.95	1.30
2004	0.75	0.91
2005	0.61	0.61
2006	0.50	0.48
2007	0.44	0.41
2008	0.39	0.37

In Table 4.7 I report the correlations between the raw per capita subscription rate and the country endowments. The year effect variable and the vintage technology variables exhibit the strongest correlations with the subscription rate. The physical size of the country and the total population of the country are not correlated with the subscription rate at either the 1 per cent or at the 5 per cent significance level. For this reason I excluded these two variables from the preliminary econometric model. However, population density measured as the total population divided by the total area in square kilometres is itself correlated with the subscription rate. All of the other country endowments are correlated with the broadband subscription rate at the 1 per cent significance level and all of the statistically significant associations are positive with the sole exception of average household size. All of the statistically significant directions of association are in accordance with expectations as forecast in Table 4.4 with the exception of the age variable.

Table 4.7: Correlations between broadband penetration and country endowments

Independent Variable	Dependent Variables	
	SubRate7 (2002 – 2008)	SubRate5 (2004-2008)
Year Effect (Year)	.697**	.562**
Household Size (House)	-.414**	-.544**
Total Land Size (Size)	-.117	-.145
Population Total (Pop)	-.026	-.057
Population Density (Dens)	.224**	.237**
Population Concentration (Concen)	.215**	.246**
Population Urbanicity (Urban)	.242**	.287**
Per Capita Income (Income)	.492**	.521**
Education: PISA Scores (EdPisa)	.264**	.328**
Education: Third Level Graduates (EdGrad)	.439**	.540**
Telephone Mainlines per 100 people in 2000 (FixTel)	.483**	.607**
Internet Subscribers per 100 people in 2000 (IntUse)	.529**	.672**
Proportion aged 60 and over (Age)	.211**	.273**

Note: $^{**}p<0.01$, $^{*}p<0.05$. SubRate7 denotes subscription rates for the seven year period from 2002 to 2008 while SubRate5 denotes subscription rates for the five year period from 2004 to 2008.

I report the correlations between the country endowments in Table 4.8 as it is important to establish whether the country endowments are independent of each other. A lack of independence between variables suggests the presence of multicollinearity between variables. According to Milfred Corlett (1990), multicollinearity is liable to lead to high variances and standard errors for the least squares estimators of the parameters. There is no overall consensus about the appropriate cut-off point above which the correlation between variables, measured in terms of the Pearson's R value, is "too high". Jay Devore and Roxy Peck (1993) and Andy Field (2003) both argue that correlations stronger than -0.80/+ 0.80 are too high. The strongest correlation between the independent variables is +0.718. This is the association between the number of fixed telephone mainlines per 100 inhabitants in 2000 and the number of Internet subscriptions per 100 inhabitants in 2000.

Table 4.8: Partial Correlations between country endowments

	Int Sub	Income	FixTel	EdGrad	House	EdPisa	Urban	Dens	Concen	Age
Year	.002	.238**	.001	.002	.000	.002	.002	.006	.006	.072
IntUse	-	.457**	.718**	.633**	-.697**	.340**	.244**	.114*	.218**	.340**
Income	-	-	.608**	.446**	-.456**	.111	.174**	-.016	.185**	.277**
FixTel	-	-	-	.647**	-.689**	.339**	.304**	.028	.320**	.437**
EdGrad	-	-	-	-	-.468**	.436**	.347**	-.062	.506**	.168*
House	-	-	-	-	-	-.479**	-.133*	-.108	.061	-.715**
EdPisa	-	-	-	-	-	-	.089	.175*	.058	.205**
Urban	-	-	-	-	-	-	-	.525**	.279**	.176*
Dens	-	-	-	-	-	-	-	-	-.311**	.210**
Concen	-	-	-	-	-	-	-	-	-	-.164*
Age	-	-	-	-	-	-	-	-	-	-

Note: $^{**}p<0.01$, $^{*}p<0.05$

Regression models for international broadband penetration

In Table 4.9 I report selected Ordinary Least Squares (OLS) regressions showing the estimated relationships between broadband penetration (2002 to 2008) and the different country endowments. OLS regression techniques are discussed in William Greene, (1990, chapters 5 and 6); Peter Kennedy, (1992, chapter 3); and Damodar Gujarati, (2003, chapter 3, pp. 58-65). I code the models estimating broadband penetration for the seven year period from 2002 to 2008 as '7X'. In Model 7A through to Model 7J I sequentially add one independent variable to the model in the order suggested by the strength of the independent variable's correlation with the raw subscription rate. Model 7U includes the age variable. Autocorrelation is tested for using the Durbin-Watson statistic. Autocorrelation will violate the ordinary least squares assumption that error terms are uncorrelated. Although autocorrelation will not bias the OLS coefficient estimates, if autocorrelation is present the standard errors will tend to be underestimated, and therefore the t-scores will tend to be overestimated. The Durbin-Watson statistic ranges in value from 0 to 4 with a value near to 2 indicating non-autocorrelation. The estimated Durbin-Watson statistics are all close to 2 meaning the residuals are not autocorrelated (Durbin and Watson, 1951). All of the reported F statistics shown in Table 4.9 are found to be statistically significant at the .01 level. The model goodness of fit value, or 'R^2', ranges from .485 when just the year effect variable is included in the model specification (Model 7A) to .866 when all eleven independent variables are included in the model specification (Model 7U). An R^2 of .866 indicates that the model explains 86.6 per cent of the international variation in broadband subscription. Overall, the regression results suggest that income per capita; average household size; PISA scores, and the degree of urbanisation are not statistically significant and robust predictors of broadband subscription.

Table 4.9 Modelling broadband penetration in the OECD, 2002 to 2008

Model	7A	7B	7C	7D	7E	7F	7G	7H	7I	7J	7U
Year	3.431**	3.427**	3.292**	3.376**	3.896**	3.388**	3.371**	3.366**	3.369**	3.356**	3.448**
IntSub	-	.549**	.494**	.387**	.345**	.335**	.344**	.342**	.282**	.254**	.184**
Income	-	-	.095**	.036	.028	.027	.039	.042	.036	.043	.027
FixTel	-	-	-	.136**	.106**	.100*	.102*	.087*	.118**	.080*	.096**
EdGrad	-	-	-	-	.128**	.130**	.103*	.077	.201**	.135**	.120*
House	-	-	-	-	-	-.461	.175	-.065	.211	-.181	-.603*
EdPisa	-	-	-	-	-	-	.022	.024	-.035	-.006	-.021
Urban	-	-	-	-	-	-	-	.043*	-.034	-.071**	-.063**
Dens	-	-	-	-	-	-	-	-	.019**	.026**	.029**
Concen	-	-	-	-	-	-	-	-	-	.120**	.123**
Age	-	-	-	-	-	-	-	-	-	-	-.478**
Const	2.3*	- 6.3**	-7.9**	-11.4**	-12.1**	-10.4**	-23.2**	-23.8**	-15.3**	-7.4**	-20.7*
R^2	.485	.764	.774	.787	.794	.795	.797	.803	.833	.851	.866
Adj R^2	.483	.762	.770	.783	.789	.788	.790	.795	.826	.843	.859
F	196.5**	334.9**	234.9**	189.5**	147.6**	130.9**	113.3**	102.5**	111.0**	113.4**	116.7**
D-W	2.296	2.007	2.075	2.014	2.091	2.089	2.113	2.090	2.25	2.190	2.249

Note: Significance of Beta Coefficient: $^{**}p<0.01$; $^{*}p<0.05$. Number of observations = 210.

I present additional model specifications in Table 4.10 and this time I only include the seven remaining statistically significant predictor variables. The age variable is not statistically significant at the .05 level (see Model 7V) and has negligible impact on the goodness of fit of the model. The ‘third level graduate’ and ‘population concentration’ variables are both found to contribute very little explanatory power to the model. The explanatory power or goodness of fit (R^2) is estimated to be .816 when just the year effect variable, the two ‘vintage infrastructure’ variables and the population density variable are included in the model (see Model 7S). However, the goodness of fit only marginally increases to .838 when both the third level graduate variable and the population concentration variable are added to the model (see Model 7Q). Despite their low marginal contribution to the explanatory power of the model I cannot reject the hypotheses that these two variables influence the international variation in broadband subscription. Nevertheless, a good model specification should combine simplicity with a great deal of explanatory power. Such models are called parsimonious models. There is often a trade-off between the explanatory power of the model and the simplicity of the model. It is important to decide at what point the incremental gain in the explanatory power of the model is no longer sufficient to justify the additional complexity of introducing additional explanatory variables. In this context, Model 7Q’s small gain in explanatory power compared to Model 7S is probably outweighed by the additional complexity of adding two additional variables to the model.

Table 4.10: Models of broadband penetration, 2002 to 2008 – coefficients for endowments

Model	7K	7L	7M	7N	7O	7P	7Q	7R	7S	7T	7V
Year	3.427**	3.426**	3.422**	3.324**	3.429**	3.425**	3.417**	3.421**	3.422**	3.427**	3.434**
IntSub	.389**	.435**	.529**	.526**	-	-	.310**	.292**	.354**	.346**	.556**
FixTel	.154**	-	-	.-	.348**	-	.115**	.123**	.168**	.120*	-
EdGrad	-	.189**	-	-	-	-	.113*	.177**	-	.135**	-
Dens	-	-	.013**	-	-	.018**	.018**	.016**	.014**	-	-
Concen	-	-	-	.062**	-	-	.068**	-	-	-	-
Age	-	-	-	-	-	-	-	-	-	-	-.049
Const	-11.5**	-8.9**	-7.7**	-8.3**	-15.0**	-.083	-16.0**	-14.6**	-13.5**	-12.1**	-5.4**
R^2	.786	.782	.790	.774	.718	.534	.838	.830	.816	.794	.764
Adj R^2	.783	.779	.787	.770	.716	.529	.833	.825	.813	.790	.761
F	252.5**	246.3**	258.3**	234.631	263.9**	168.6**	174.8**	198.6**	227.6**	197.2**	222.7**
D-W	1.972	2.132	2.113	2.039	1.894	2.241	2.114	2.173	2.079	2.064	2.000

Note: Significance of Beta Coefficient: $^{**}p<0.01$; $^{*}p<0.05$. Number of observations = 210.

Selected regression results for the 2004 to 2008 dataset are reported in Table 4.11. Models of broadband penetration reflecting the five year period covering 2004 to 2008 are all coded ‘5X’. Autocorrelation is present when the ‘year effect’ variable is excluded from the model. This means that findings of significance must be considered unreliable in model specifications that exclude the year effect variable. The average household size; the per capita level of income, the PISA scores, and the urbanicity level are again all rejected as statistically significant predictors of the subscription rate. The model’s goodness of fit (R^2) is .800 when just the year effect variable and the two vintage infrastructure variables are included (see Model 5C). However, the model’s goodness of fit increases only marginally to .828 when every predictor variable except population density and age are included (see Model 5I). The inclusion of population density improves the model’s goodness of fit to .871. The findings of statistical significance are not found to be robust for the ‘fixed telephone’, ‘third level graduate’, and ‘geographic concentration’ variables.

Table 4.11: Modelling broadband penetration in the OECD, 2004 to 2008

Model	5A	5B	5C	5D	5E	5F	5G	5H	5I	5J	5U
IntSub	.670**	.487**	.487**	.461**	.410**	.412**	.423**	.420**	.419**	.378**	.264**
FixTel	-	.177**	.177**	.160**	.120**	.094*	.096*	.078	.063	.069	.086*
Year	-	-	3.740**	3.740**	3.740**	3.658**	3.641**	3.633**	3.631**	3.627**	3.77**
House	-	-	-	-1.183	-1.462	-1.363	-.672	-.930	-1.600	-2.375*	-7.15**
EdGrad	-	-	-	-	.137**	.129*	.099	.070	.034	.116*	.100
Income	-	-	-	-	-	.057	.069	-.074*	.076*	.071*	.056
EdPisa	-	-	-	-	-	-	.024	.026	.027	-.002	-.017
Urban	-	-	-	-	-	-	-	.047*	.045*	-.058**	-.057*
Concen	-	-	-	-	-	-	-	-	.038	.121**	.124**
Dens	-	-	-	-	-	-	-	-	-	.024**	.027**
Age	-	-	-	-	-	-	-	-	-	-	-.502**
Constant	5.4**	-.5	-15.5**	-11.1*	-10.8*	-11.0**	-24.9*	-25.7**	-24.4*	-10.0	-19.4
R^2	.452	.484	.800	.802	.811	.814	.817	.825	.828	.871	.889
Adj R^2	.448	.477	.796	.796	.804	.806	.808	.816	.817	.861	.881
F	122.1**	68.9	194.9**	145.7**	123.4**	104.4**	90.7**	83.3**	74.8**	93.6**	100.9**
D-W	0.845	0.735	1.862	1.845	1.947	2.012	2.039	1.968	1.947	1.993	2.105

Note: Significance of Beta Coefficient: $^{**}p<0.01$; $^{*}p<0.05$. Number of observations = 150. Income is per $1,000.

I present additional model specifications in Table 4.12 but this time only include the seven statistically significant predictor variables from Table 4.11. The age variable is not found to be statistically significant at the .05 level and only very marginally improves the goodness of fit of the model (see Model 5V). When the six remaining independent variables are included in the model specification the goodness of fit is .851 (see Model 5P). The goodness of fit only marginally diminishes when either the ‘third level graduates’ variable (R^2 =.846) or the ‘geographic concentration’ variable (R^2 = .844) are excluded from the model specification. Excluding both of these variables reduces the explanatory power of the model by slightly over 2 percentage points (R^2 = .830).

Table 4.12: Models of broadband penetration, 2004 to 2008 – coefficients for endowments

Model	5K	5L	5M	5N	5O	5P	5Q	5R	5S	5V
Year	3.740**	3.740**	3.740**	3.732**	-	3.732**	3.732**	3.733**	3.732**	3.769**
IntSub	-	.670**	-		.453**	.408**	.448**	.392**	.453**	.411**
FixTel	-	-	.419**	.-	.190**	.139**	.160**	.146**	.190**	.163**
EdGrad	-	-	-	-	-	.116*	-	.174**	-	.113*
Dens	-	-	-	.018**	.014**	.017**	.017**	.015**	.013**	.018**
Concen	-	-	-	-	-	.061**	.083**	-	-	.050*
Age	-	-	-	-	-	-	-	-	-	-.150
Constant	.9	-9.5**	-	-1.5	-2.5	-19.8**	-19.6**	-18.5**	-17.4**	-17.8**
R^2	.316	.768	.684	.371	.515	.851	.846	.844	.830	.854
Adj R^2	.312	.765	.680	.362	.505	.845	.841	.839	.825	.847
F	68.5**	243.8**	159.3**	43.3**	51.6**	136.4**	158.3**	155.9**	177.0**	119.0**
D-W	2.332	1.944	1.773	2.235	.672	1.906	1.849	1.982	1.883	1.912

Note: Significance of Beta Coefficient: $^{**}p<0.01$; $^{*}p<0.05$. Number of observations = 150.

In Table 4.13 I report collinearity diagnostics for the remaining independent predictor variables. Collinearity diagnostics are undertaken to test for multicollinearity between variables. There is an implication that there may be extraneous variables in the model if multicollinearity is found to be present. In particular, there is cause for concern if the Variance Inflation Factor (VIF) is greater than ten or if the tolerance is less than 0.1 (Myers, 1990). If either threshold is breached then the regression results may be biased. The diagnostics show no evidence of multicollinearity.

Table 4.13: Collinearity statistics for country endowments

2002-2008	Tolerance	VIF	2004-2008	Tolerance	VIF
Year Effect	1.000	1.000	Year Effect	1.000	1.000
Internet subscriptions in 2000	0.416	2.403	Internet users in 2000	0.416	2.403
Telephone mainlines in 2000	0.420	2.379	Telephone mainlines in 2000	0.420	2.379
Proportion with 3rd level quals.	0.421	2.378	Proportion with 3rd level quals.	0.421	2.378
Population density	0.869	1.151	Population density	0.869	1.150
Population concentration	0.655	1.526	Population concentration	0.656	1.525

I present a set of well-fitting parsimonious models of broadband penetration in Table 4.14. For comparative purposes I show model estimates for the 2006 to 2008 period. The model estimates for the three year period spanning 2006 to 2008 are all coded ‘3X’.The geographic concentration variable is not found to be a statistically significant predictor of broadband penetration when the dataset is restricted to the years 2006 to 2008. The overall estimates are reported separately for 2002 to 2008, for 2004 to 2008, and for 2006 to 2008. In each case I also report the estimates when the geographic concentration variable is excluded from the model.

Table 4.14: Beta coefficients for the parsimonious models of broadband penetration

	2002-08		2004-08		2006-08	
Model Name	7Q	7R	5P	5R	3A	3B
Year Effect	3.417**	3.421**	3.732**	3.733**	3.330**	3.330**
	(.139)	(.142)	(.215)	(.219)	(.467)	(.469)
	[24.550]	[24.035]	[17.398]	[17.055]	[7.126]	[7.099]
Internet subscriptions per 100 people in 2000	.310**	.292**	.408**	.392**	.487**	.477**
	(.046)	(.046)	(.050)	(.050)	(.063)	(.062)
	[6.801]	[6.312]	[8.202]	[7.779]	[7.781]	[7.649]
Telephone mainlines per 100 people in 2000	.115**	.123**	.139**	.146**	.172**	.176**
	(.031)	(.032)	(.034)	(.035)	(.043)	(.043)
	[3.666]	[3.849]	[4.035]	[4.175]	[3.977]	[4.078]
Third level qualifications (%) – age 25 to 64	.113*	.177**	.116*	.174**	.115	.150*
	(.048)	(.044)	(.052)	(.048)	(.065)	(.060)
	[2.365]	[3.996]	[2.236]	[4.175]	[1.751]	[2.516]
Population density per square kilometre	.018**	.016**	.017**	.015**	.014**	.012**
	(.002)	(.002)	(.003)	(.003)	(.003)	(.003)
	[7.362]	[6.556]	[6.387]	[5.749]	[4.074]	[3.847]
Population's Geographic Concentration	.068**		.061**		.038	
	(.021)		(.023)		(.029)	
	[3.211]		[2.632]		[1.297]	
Constant	-16.01**	-14.59**	-19.77**	-18.49**	-19.09	-18.302
R^2	.838	.830	.851	.844	.847	.844
Model F	174.773**	198.601**	136.383**	155.856**	76.423**	90.634**

Note: Standard errors are shown in parentheses. The t statistics are shown in square brackets. ** denotes significance at the 0.01 level. * denotes significance at the 0.05 level.

The period from 2004 to 2008 is the most representative of the main broadband diffusion process in the OECD as a whole. The parsimonious model for the 2004 to 2008 period are presented in Table 4.14 as model 5P ($R^2 = 0.851$) and model 5R ($R^2 = 0.844$). Model 5R excludes the geographic concentration variable and is expressed as:

$$EPR_i = -18.49 + 3.733(Year_i) + 0.392(IntSub_i) + 0.146(FixTel_i) + 0.174(EdGrad_i) + 0.015(Dens_i) + \varepsilon_i \tag{4.4}$$

Where

EPR_i is the Expected penetration rate for country i

According to the estimated beta coefficient the number of broadband subscriptions increases by an estimated 3.7 percentage points for each year of time elapsed since the start of the diffusion process (see Model 5R). The high year-on-year increase in penetration rates is consistent with our apriori expectations for a successful technology passing through its rapid diffusion phase. In the longer term the early mover advantage may diminish over time as countries gradually start to enter the slower and more mature phase of the diffusion process. Countries with more developed pre-broadband telephone networks and with higher levels of narrowband Internet usage in 2000 have been more successful at achieving high penetration rates for broadband. I estimate that each additional Internet subscription per 100 persons in 2000 subsequently increases the broadband penetration rate in 2008 by 0.392 percentage points. Each additional telephone mainline per 100 persons in 2000 increases the broadband penetration rate in 2008 by 0.146 percentage points. These positive effects may reflect lower post-2000 investment costs for broadband infrastructure provision and/or increased consumer awareness of and preference for telecommunications services. On the other hand, superior 'vintage technology' indicators may themselves reflect the presence of better suited institutions and policies in certain countries. If so, to the extent that they persisted, such institutions and policies may also have facilitated broadband penetration in the twenty first century. The estimates also show that 100 additional inhabitants per square kilometre increase the penetration rate for broadband by 1.5 percentage points. While Ireland's relatively low population density disproportionately inhibited the rate of broadband penetration relative to the OECD, the actual negative impact of the population density differential is estimated at just 0.7 percentage points. Finally, each 10 percentage point increase in the proportion of 25-to-64 year olds with third level qualifications is estimated to increase the broadband penetration rate in 2008 by 1.74 percentage points.

Estimates of broadband efficiency

To estimate each country's relative broadband performance I generate a broadband efficiency score for each country. The country's efficiency score is the ratio between the country's Actual Penetration Rate (APR) and the country's Expected Penetration Rate (EPR). Each country's EPR is estimated separately using the beta coefficients generated in the parsimonious models described in Table 4.14. I report each country's 2008 efficiency score in Table 4.15. The scores shown in Table 4.15 are generated using the Model 5R coefficients (see Table 4.14). Luxembourg, Iceland, Finland and Norway achieve the strongest efficiency scores, while Mexico, Turkey, Greece and Poland achieve the weakest efficiency scores. The eleven highest scores are all obtained by European countries. Ireland obtains a below average efficiency score of 0.894. This was the ninth weakest efficiency score in the OECD in 2008 and suggests that Ireland's slow broadband market development is not entirely attributable to Ireland's relatively disadvantageous endowment set. I conclude that other factors not included in the empirical model are at least partially responsible for Ireland's low subscription rate.

Table 4.15: Broadband efficiency scores in the OECD, 2008

Country	**Rank**	**Efficiency**	**Country**	**Rank**	**Efficiency**
Luxembourg	1	1.301	Switzerland	16	0.963
Iceland	2	1.300	Germany	17	0.952
Finland	3	1.246	Portugal	18	0.9328
Norway	4	1.206	Slovak Republic	19	0.9326
France	5	1.163	Australia	20	0.913
Netherlands	6	1.092	New Zealand	21	0.901
Hungary	7	1.085	**Ireland**	**22**	**0.894**
Spain	8	1.035	United States	23	0.883
Sweden	9	1.028	Czech Republic	24	0.879
Denmark	10	1.026	Japan	25	0.773
Austria	11	1.018	Italy	26	0.771
South Korea	12	1.010	Poland	27	0.717
Belgium	13	1.004	Greece	28	0.631
Canada	14	0.989	Turkey	29	0.579
United Kingdom	15	0.987	Mexico	30	0.460

The precise efficiency score obtained for each country will vary marginally depending on the chosen model specification. In Table 4.16 I report Ireland’s broadband efficiency score for each of the four main model specifications presented in Table 4.14. I find that Ireland’s efficiency score ranges between 0.894 and 0.954 with the exact score obtained contingent on the particular model specification used. This suggests that Ireland is indeed underperforming relative to the OECD in terms of broadband penetration

Table 4.16: Broadband efficiency scores for Ireland, 2008

Model	7Q	7R	5P	5R
Predicted Rate	20.027	21.143	20.395	21.377
Efficiency	0.954	0.904	0.937	0.894

An efficiency score of 1.00 represents an average performance. Higher efficiency scores represent better than average performance while lower efficiency scores represent below average performance.

4.5 Conclusion

So how do our empirical findings contribute to an understanding of Ireland's broadband market development? I find that over 80 per cent of the international variation in broadband penetration is explained by the cumulative impact of non-policy related national country endowments and the timing of a country's broadband take-off. The results imply that Ireland's relatively low population density and relatively low rate of early narrowband Internet diffusion were both inhibiting factors that disproportionately constrained broadband penetration in Ireland relative to the OECD. There is some evidence that Ireland's high level of population dispersion had a negative impact although this result is not found to be robust. The broadband penetration rate is also positively associated with higher diffusion rates for telephone mainlines in 2000 and with higher rates of third level qualifications in 2004. However, as Ireland is close to the OECD median for both of these indicators Ireland cannot be described as having been disproportionately constrained by either variable. The main result is that Ireland's broadband penetration rate in 2008 was less than the expected penetration rate given Ireland's particular set of national country endowments. Based on this finding Ireland's trailing of the OECD must be partially explained by additional reasons not incorporated within the empirical model. Overall there is evidence that Ireland is indeed underperforming. In the next chapter I consider the development of the network infrastructure in the twentieth century in order to investigate whether Irish underperformance has its roots in the pre broadband era.

Chapter Five: The Evolution of Ireland’s Telephone Capital Stock, 1922 to 1997

5.1 Introduction

In most OECD countries broadband Internet access is usually obtained via the telephone network infrastructure. In this chapter the focus shifts to the pre broadband era and in particular to the period from Irish Independence up until the privatisation of the telephone network near the end of the twentieth century. The core empirical exercise undertaken is the construction of a set of partially disaggregated capital stock estimates for the Irish telephone network from 1922 to 1997. The method used is the Perpetual Inventory Method (PIM). This method was pioneered by Raymond Goldsmith in 1951 and has been applied by many others in the meantime (see for example Hofman, 2000; Vaughan, 2001; and Keeney, 2007). The telephone network was under either the direct or the indirect control of the Irish state for the entirety of this period. The privatisation of Ireland’s telephone network operator at the end of the twentieth century coincided with the take-off of broadband in the OECD. Partial privatisation of the network began in 1996 and the network operator Telecom Éireann was fully privatised in 1999 and renamed as Eircom plc. By 1997 there were over 1.4 million telephone exchange lines in the country (Redmond and Heanue, 2000). The decision to privatize the network was a reversal of the earlier policy of nationalization adopted by the United Kingdom governments of the 1890s and 1900s. These earlier policies had come to fruition with full nationalization of the British and Irish telephone networks in 1912.

The chapter four results justify focussing on Ireland’s pre broadband telecommunications infrastructure. These results suggest that the quality of the vintage, i.e. pre broadband, telecommunications infrastructure influenced the subsequent levels of broadband diffusion. The results also indicate that there is a positive link between the early diffusion of dial-up narrowband Internet and the subsequent diffusion of the more advanced broadband Internet. One implication is that history and path dependency matter. In particular the pre broadband context, including the prevailing telecommunications infrastructure, appears to be an important part of the story of broadband market development. The construction of historical datasets is valuable on its own terms because it allows us to observe long-term trends and to identify any recurring patterns that may exist. Historical patterns in the development of the telephone network infrastructure may provide clues about the likely future development of fixed broadband network infrastructure, particularly given the close market and technological similarities between these two telecommunication services.

It is argued that the privatization of the network infrastructure was a strategic mistake by the Irish government because Eircom's low levels of investment in the network infrastructure may have slowed broadband diffusion, and reduced the availability and quality of broadband services in Ireland (see for example Sweeney, 2004; Palcic and Reeves, 2011). The counterfactual is of course unknowable. We cannot 'rerun' the experiment to find out what Ireland's broadband market indicators (e.g. price, speed, availability and penetration) would have been like if the network infrastructure remained under direct or indirect state control. However, we can obtain clues about what investment in broadband infrastructure might have looked like by observing historical patterns of investment in the telephone network for the period when the network infrastructure remained under Irish state control. The controversy surrounding the decision to privatize the then Telecom Éireann provides ample motivation for the construction of a constant price adjusted dataset of annual telephone capital additions for the pre privatization era.

The basic strategy is to use the Perpetual Inventory Method (PIM) to estimate the year-on-year growth of the telephone network infrastructure while it remained under state control. The PIM is the standard method of estimating capital stock levels used in the literature (OECD, 2001b). As explained by André Hofman (2000, p.46), the PIM works by cumulating historical series of past investment flows and then deducting assets which are scrapped, depreciated, written off or destroyed. The method is useful as it permits an analysis of the composition and the age distribution of the capital stock and also because it permits an international comparison of capital stock levels. Data for annual capital additions; a base estimate of the starting capital stock, and data for annual capital goods price indices, are all required for a successful application of the PIM method of capital stock estimation. I obtain disaggregated data for the annual telephone capital additions made before 1981 from the annual reports of the Department of Posts and Telegraphs. The data for capital additions from 1981 to 1983 is obtained from the Irish government's annual *Estimates for Public Services*, while the data for 1984 onwards comes from the annual reports of Telecom Éireann. Data for capital goods price indices is obtained from the statistical abstracts of the Department of Industry and Commerce and the Central Statistics Office. An appropriate capital depreciation function and appropriate estimates for the asset service lives are also required. For the purposes of this exercise I use a geometric depreciation function.

I find that the annual level of telephone capital additions peaked in 1981 at IR£424 million (all figures here are expressed in constant 2000 prices). At the other extreme, telephone capital additions were less than IR£1.5 million in 1923, 1932, 1933, 1942 and 1944. According to the PIM estimates the telephone capital stock reached its lowest levels of just under IR£20 million in 1934 and 1935. The capital stock fluctuated close to its pre Independence level for over twenty years following Independence and only permanently exceeded its pre Independence level in 1946. The first major expansion in investment occurred from the mid-1940s to the early 1950s. Annual capital additions increased almost sevenfold between 1944 and 1947 and over thirtyfold between 1944 and 1951. Following a decade of stagnating investment levels in the 1950s, the annual level of capital additions then began to rise slowly from the 1960s onwards. The second major expansion in investment occurred at the end of the 1970s and annual capital additions more than doubled between 1979 and 1981. The surge in investment continued for the first half of the 1980s before declining again to late 1970s levels by 1985. Annual investment then remained relatively stable until the mid-1990s at which point it started to rise rapidly prior to privatization. Total telephone capital additions in 1996 were fifty per cent higher than the 1994 level.

The total telephone capital stock was just over £24 million in 1922, exceeded IR£100 million for the first time in 1952, exceeded IR£1 billion for the first time in 1980, and peaked at over IR£1.8 billion in 1984. However, the PIM estimates show that the telephone capital stock was just over IR£1.5 billion in 1997. How should we interpret this finding? These findings do not mean that the telephone network infrastructure was more developed in 1984 than 1997. One reason is that the capital stock estimates reflect the costs of inputs and not the actual value of resources. Due to technological change capital additions made in later years are likely to be more advanced and/or more productive than capital additions made in earlier years. Improvements in the productivity of capital assets may be especially pronounced in the case of information technologies. Thus capital stock estimates, while useful, are limited as a measure of the development and quality of the network, and should only be considered indicative for those purposes. So what can the estimates tell us?

The estimates show that growth in annual capital additions was not continuous over time and often fluctuated wildly from year-to-year. In particular, investment appears to have been pro-cyclical and highly reliant on the underlying strength of the economy. The capital stock was actually lower in 1945 than it was in 1922. This suggests that provision of telephone services was not a priority of government during this period. As I discuss later in the chapter, there were two periods of fast growth in annual capital additions (the mid-1940s and the early 1980s). Both surges in investment followed scathing official attacks on the quality of the network infrastructure as well as years of growing pressure from the public and from business groups. Thus an assumption overall investment in broadband infrastructure in the early twenty first century would have been higher if the network had been under state control is not necessarily supported by the historical experience of investment levels in the twentieth century.

5.2 The Development of the Irish Telephone Network

Cormac O'Gráda (1997, p. 187) argues that Ireland's small and dispersed population has always posed particular problems for developing telecommunications infrastructure outside of the towns and cities. The chapter four estimates appear to support O'Gráda's argument as they indicate that population density and population concentration are both postively associated with higher levels of broadband penetration. Ireland's relatively small, low density, and dispersed population increases the per capita costs of providing telephone and related services, thereby reducing the profitability of service provision in Ireland compared to the OECD. This not only damages the commercial case for investing in modern broadband infrastructure in the twenty first century, but also diminished the state's rate of return from investing in the telephone network in the twentieth century.

The telecommunications service was administered by the Department of Posts and Telegraphs from 1923 until 1984, when the Department was abolished in its existing form, with responsibility for telecommunications services transferred to Telecom Éireann, a new semi-state body. The semi-states are Irish state owned enterprises operating under a commercial mandate and independent of the civil service. Telecom Éireann (later Eircom) was initially part privatized in 1996 and then fully privatized on 8 July 1999 when the state sold all of its shares in the company. It was Ireland's largest company at the time and valued at €8.4 billion (Sweeney, 2004, p.63). Eircom's subsequent level of capital investment in telecommunications infrastructure was criticised as very low (Sweeney, 2004, p. 75) and insufficient even to replenish its asset depreciation in each year after 2001 (Palcic and Reeves, 2011, p.165). Eircom's low level of investment may well have inhbited the development of the broadband market and broadband availability and quality. However, there is no certainty that investment levels would have been higher under the counterfactual of state control. As we saw in chapter four, Ireland was already trailing the OECD in terms of Internet diffusion at the time Telecom Éireann was privatized. This suggests that reasons for Irish underperformance may very well pre-date the privatization of the network infrastructure.

Pre Independence telephonic communication in Ireland

Ireland's new Free State Government inherited a weak telephone network from the British administration in 1922. Different aspects of the development of telephonic communication in Ireland during the pre-broadband era have been discussed by a number of authors, and in this section I draw on A. J. Litton (1961); Eamonn Hall (1993); Roderick Flynn and Paschal Preston (1999); as well as O'Gráda (1997) and James Burnham (2003). Until the mid-nineteenth century, long distance communication within Ireland was little different from that of two thousand years ago, and was still based on horseback by land and on boat by river and sea. Hans Christian Oersted discovered and harnessed electro-magnetic energy in 1819 and this discovery was later used to influence a magnetised needle to ring a bell. William Cooke and Charles Wheatstone (C&W) subsequently obtained a patent in 1837 for an electric alarm and telegraph system capable of harnessing electric current to transmit messages over wires. The C&W system was initially used on the English railways for signalling and for timekeeping. By the 1840s the system was extended so the public were able to send private telegrams (Standage, 1998). In 1845 Samuel Morse used an advanced version of the C&W patent to electrically transmit a telegraphic message along a wire from Washington DC to Baltimore. The privately owned English and Irish Magnetic Telegraph Company was incorporated in 1851to provide telegraph lines between England and Ireland. Private investment in the Irish telegraph network continued throughout the 1850s and 1860s. However, the Telegraph Acts of 1868 and 1869 authorised the Postmaster-General to acquire the whole or part of the business of any telegraph company for an agreed sum, and soon thereafter the state became the monopoly provider of telegraph services in the United Kingdom (Hall, 1993, p.96).

Alexander Bell was awarded patent rights for an electronic speech machine in 1876 which later became known as the telephone. By 1879 private telephone companies had been set up in the United Kingdom to exploit the telephone's commercial opportunities (Litton, 1961, p.80). The first telephone exchange in Ireland was opened in 1880 by the United Telephone Company at Commercial Buildings in Dame Street in Dublin. The company had five initial subscribers (Redmond and Heanue, 2000). In 1884 the first trunk routes in Ireland were installed between Dublin and Belfast (Connolly, 2007). Trunk routes enabled callers to contact people connected to different telephone exchanges around the country and were therefore a prerequisite for a genuinely national communication system. However, the telephone network was to develop slowly. By 1888 there were only 500 telephone lines and three sub-exchanges in the whole of Dublin (Hall, 1993, p.37), and until a telephone link between Belfast and Scotland was opened via submarine cable in 1893, there was no permanent connection external to the island (Litton, 1961, p.83). Telephone services do not appear to have been considered a necessity by the Government. The Chancellor of the Exchequer declaring:

> Telephonic communication was not desired by the rural mind (Post Office Records, 1901, June 11 – see Hall, 1993, p.38).

By 1900 the newly opened Crown Alley Dublin exchange had a capacity for 1,600 lines and there were 56 telephone exchanges in operation on the island. Telephone services became more affordable to a much wider residential market when metered services were introduced in 1907 as an alternative to a fixed annual subscription (BT Archives, 2009).

The optimal market structure for telephone services has long been a matter of debate. In the mid-nineteenth century Antoine Cournot (1838) and Jules Dupuit (1844) had argued there were some industries and services where a monopoly was likely to form as a matter of course and where competition would actually be destructive. Such industries or services could be identified by the presence of decreasing average costs and increasing returns to scale (Baumol, 1977). Eammon Hall (1993) describes the evolving nature of the debate which I recount here. In 1882 the British Post Office declared that monopoly in the telephone industry was not in the public interest, and that competition between telephone companies should be encouraged. However, by 1889 the National Telephone Company (NTC) was in the process of constructing a private monopoly through a combination of patent control and the buying or forcing out of rivals. As the 1890s progressed, the British Government became increasingly convinced the provision of telephone services was a natural monopoly, and that competition might not after all be the most efficient market structure for network based telecommunications. The House of Commons Select Committee considered the telephone service to be:

> ...already so essential to commercial men...benefiting directly or indirectly all classes of the community...ought no longer to be treated as the practical monopoly of a private company (Report from the Select Committee on Telephones, HMSO, 1898, p. 2 See Hall, 1993, p.102).

In 1901 the Government announced a plan to nationalise the NTC's monopoly network. The Government declared the NTC's license would not be renewed when it expired in 1912 and following arbitration the NTC was eventually paid £12.5 million in recompense by the state (Litton, 1961, p.84). Once the NTC had secured an agreed price from the Government for its telephone network infrastructure, it is difficult to see what incentive the NTC would have had to make new capital purchases to upgrade and expand the network, or indeed even to invest in maintaining the existing network. With little or no economic rationale for the NTC to invest, the quality of the network gradually deteriorated so that by 1912 the equipment that was eventually taken over by the Post Office was in a general state of disrepair.

Capital investment in the telephone network remained low following nationalisation in 1912 because the pressures of the First World War diverted substantial resources to the military between 1914 and 1918. Priority for investment in telecommunications infrastructure was given to Great Britain at Ireland's expense. As an example, while Britain had already opened its first automatic exchange by 1912, Ireland did not receive funding for even one automatic exchange prior to achieving independence (Connolly, 2007). There were still no telephone exchanges in Mayo, Leitrim and Roscommon by the time the First World War ended in September 1918, while Longford had just one telephone exchange (Hall, 1993, p.40). The quality of the network was diminished even further when parts of the telephone infrastructure were damaged in the War of Independence and the Civil War. For all these reasons the new Free State Government inherited a weak telephone network in 1922 and at the time of Independence only a single exchange in the country, located in Ballsbridge in Dublin, had post-NTC-era switchboard equipment. In total the new administration inherited 194 telephone exchanges with 19,037 lines and 553 call offices.

The post-Independence telephone network in Ireland

A combination of economic stagnation and tight fiscal policy in the 1920s and early 1930s reduced the state's capacity to invest in the network. The first automatic exchange in Ireland was not completed until 1927 (Connolly, 2007) and as we will see in the empirical section the value of the capital stock was not to exceed pre Independence levels until the late 1930s. Fiscal constraints were particularly tight during the Second World War and all planned extensions to the network were abandoned during the war years (Litton, 1961, p.86). The Cabinet Committee on Economic Planning undertook a comprehensive review of the network in 1946 and found the state of the telephone service to be lacking. The Department of Posts & Telegraphs defended itself, arguing there was insufficient demand to justify a major increase in expenditure (Dept. Posts and Telegraphs, 1946, October 21). Higher levels of investment in telephone infrastructure did not begin in earnest until 1948. Despite increasing investment very few houses in Ireland had a telephone by the middle of the century (Redmond and Heanue, 2000) and annual levels of investment in the telephone infrastructure subsequently stagnated throughout the 1950s.

A waiting list for telephone subscription emerged in the late 1940s and was eventually to peak at 100,000 applicants in 1980 (Flynn and Preston, 1999, p.554). Hall (1993, p.59) reports that telephone density was the lowest in Europe in 1973, with only 12 telephones per 100 of the population, and with an eighteen month waiting list to receive a connection. By comparison, France had the second lowest rate in Western Europe in 1973 with 19 telephones per 100 of the population. The Minister of the Department of Posts & Telegraphs described his own department’s policy in relation to the development of the telephone service as “stop-go” (Dáil Debates, 1973, December 4, col. 869). Although Flynn and Preston (1999, p.549) find that there was a spike in capital spending on the Irish telephone system in the mid-1970s, Burnham (2003, p. 542) argues that Ireland’s telecommunications system was perhaps the worst in Western Europe by the end of the 1970s and characterised by erratic service, chaotic billing, excessively high charges and a typical wait time for residential installation of over a year.

A special independent inquiry lead by M. J. Dargan was set up by the Government to investigate the situation. The Report of the Telegraphs Review Group 1978-79, known as the Dargan Report (1979), documented the inadequacies of the Department of Posts & Telegraphs so remorselessly that it made radical structural change inevitable (Lee, 1989). The Dargan Report attacked the Department of Posts and Telegraphs for making no effort to sell telephones, and accused the Department of practice designed to contain the enormous latent demand within manageable limits. It argued:

> ...the state of the telecommunication carrier service generally constituted a crisis (Report of Posts and Telegraphs Review Group, 1979, p.1).

Pressure for change was also coming from other sources including business interests and consumers. For example, the Industrial Development Agency was working to convince the government of the importance of a high quality telecommunications system for job creation and for multinational investment in Ireland (Burnham, 2003, p.543). There was a fundamental shift in telecommunications policy following the Dargan Report, with the Government announcing it would substantially increase the annual levels of investment on telecommunications infrastructure. The telephone service network was gradually prepared for eventual transfer from the Department of Posts & Telegraphs to the commercially driven Telecom Éireann. This transfer was finally completed in 1984. In addition, the decision was taken at Government level to commit to eventually privatizing the network, thus reversing the policy of nationalization adopted by the United Kingdom government in the 1890s.

Why were telephone services in Ireland so poor compared to the rest of Western Europe? Ireland's low population density meant there was a relatively low rate of return on investment. This may have disincentivised investment in the telephone service thereby contributing to a slow rate of improvement in the quality and scale of the network infrastructure. In addition, the often weak economic position of the country worked against large-scale increases in investment spending particularly in areas that might not have been considered a priority. The often sharp annual fluctuations in capital investment suggest that the telephone network was not a core priority of Government. The development of the network infrastructure appears to have been highly dependent on the health of the Government's finances. When resources were tight the capital budget seems to have been cut, thus creating a 'stop-go' effect. This behaviour has been replicated in the post 2008 fiscal crisis with Government disproportionately cutting voted capital spending compared to voted current spending. Hall (1993) and Flynn and Preston (1999) argue that the problems in establishing the telephone network in Ireland were primarily supply side issues. They point to the lengthy waiting lists of up to 18 months for a telephone line subscription as evidence that the slow diffusion of telephone services was caused either by an inability or lack of desire on the part of the Department of Posts and Telegraphs to match prevailing demand.

One criticism of the decision to fully privatize the telephone network at the end of the 1990s relates to the argument that privatization caused underinvestment in the network infrastructure (Sweeney, 2004; Palcic and Reeves, 2011), and that this underinvestment had knock-on effects for broadband availability and quality. It is impossible to know what would have happened in the twentieth first century under the counterfactual of state control.

However, it is possible to investigate levels of capital investment in the telecommunications infrastructure for the period when the network was under Irish state control. The findings from such an exercise may provide clues about what the development of the network infrastructure might have looked like under state control in the twenty first century. So how can we measure the development of the network infrastructure during the twentieth century?

5.3 Strategy for Estimating Telephone Capital Stock: The Perpetual Inventory Method

One way to quantify the development of the network infrastructure is to estimate changes in the value of the telephone capital stock over time. The Perpetual Inventory Method (PIM), which was pioneered by Raymond Goldsmith (1951), is the standard method of capital stock estimation in the economics literature (OECD, 2001b). Goldsmith's method for measuring the capital stock works by cumulating historical series of past investment flows and deducting assets which are scrapped, depreciated, written off or destroyed (Hofman, 2000, p. 46). Goldsmith's method is popular because it permits an analysis of the composition and the age distribution of the capital stock (Hofman, 2000) and perhaps most usefully because it permits comparison with other countries. Michael Ward (1976), Dan Usher (1980) and the OECD (2001b) have all developed PIM methodologies for capital stock estimation and the PIM is widely used in the empirical literature. For example, André Hofman (1992 and 2000) uses a variation of the PIM to construct capital stock estimates for six Latin American countries, while R.N. Vaughan (1980), E.W. Henry (1989) and Mary Keeney (2007) have constructed capital stock estimates for Ireland. Hibbert, Griffon and Walker (1977) and Nicholas Oulton (2001) have constructed capital stock estimates for the United Kingdom, while Mas, Perez and Uriel (2000) have done so for Spain, and Allan Young and John Musgrave (1980) have done so for the United States.

According to Mary Keeney (2007, p. 30) there are two potential weaknesses with PIM models. The first concern relates to deficiencies due to data inputs, while the second concern is methodological and relates to the PIM's assumption of no net appreciation or after-purchase revaluation of assets. There are a number of methodologies other than the PIM for measuring capital stock levels. For example, Hernandez and Mauleon (2005) describe econometric models used to indirectly measure capital stocks jointly with the production function. Company surveys will often take a 'direct' measurement of the capital stock for a benchmark year by using surveys of physical assets, insured values, company book values or stock exchange values. However, according to the OECD (2001b), such survey methods are problematic for a number of reasons. In particular, the conventional method of calculating depreciation with reference to the historical cost of assets will underestimate the level of depreciation if inflation is present. Although estimates of the telephone capital stock are limited as measures of telephone market development, they are nevertheless useful as proxies for investment in the network, and therefore a good measure of the priority afforded to the telephone network during the period of state control. In the current study I use the PIM estimates to construct a dataset showing the year-on-year changes in Ireland's telephone capital stock, and changes in its composition, from Independence to privatization. So how is the PIM performed?

The Perpetual Inventory Method (PIM)

The PIM was first developed by Goldsmith (1951) and is the method of capital stock estimation recommended by the OECD (2001b). In addition to annual estimates for the total value of the telephone network's capital stock, the constructed data set also contains estimates of the capital stock's composition and age distribution over time. The unreliability of the capital stock estimate for the first year of the data set becomes less important over time. The reason is that capital additions made before the initial year of the data set comprise a smaller and smaller proportion of the total capital stock for each subsequent year that passes. The value of the capital stock for any given year *t* is calculated in the following way: First, the inflation adjusted value of the capital stock for year *t-1* is taken as the base estimate for year *t*. Second, the base estimate is then adjusted using a pre-defined depreciation function which takes account of the depreciating value of the year *t-1* capital stock. Third, the net value of capital additions in year *t* is added to the depreciated value of the year *t-1* capital stock. The result is the estimated value of the capital stock for year *t*. The capital stock will increase if the total value of net investments in year *t* exceeds the total value of depreciation in the year *t-1* capital stock over the course of year *t*.

Step one: Compiling annual net capital additions

What is meant by the capital stock? According to convention (OECD, 2001b), capital stock estimates only consider tangible, durable and reproducible assets. (a) Tangible assets are physical artifacts such as telephone poles or machinery. Non-physical assets, for example ideas and patents, are not considered part of the capital stock. (b) Durable assets are physical artifacts with a typical service life in excess of one year, for example trucks and buildings. Artifacts with service lives of less than a year, for example light bulbs and pens, are not considered part of the capital stock. (c) Reproducible assets are artifacts that can be used repeatedly (at least twice) in the productive process, for example machine tools. One-shot inputs into the productive process, for example coal, oil and gas, are not considered part of the capital stock. The capital stock is itself subdivided into three groups of artifacts. Residential structures and non-residential structures are together categorized as non-transportable assets while the third group of artifacts, made up of machinery and equipment, is categorized as transportable assets. Transportable assets tend to have much shorter service lives than non-transportable assets (BEA, 2003).

To construct year-on-year capital stock estimates we require a benchmark or base estimate of the capital stock for the first year of the series as well as data for Gross Fixed Capital Formation (GFCF) for each subsequent year. GFCF does not account for the depreciation of fixed assets, and represents the value of acquisitions of new or existing fixed assets, less disposals of fixed assets. Financial assets are excluded from the measure of GFCF. The estimate for the base year of 1922 was obtained from the Statistical Abstract of the Department of Industry and Commerce (1931). The 1923 to 1980 GFCF data for the telephone network was obtained from the Annual Reports of the Department of Posts and Telegraphs. GFCF data from 1981to 1983 was taken from the Government’s Estimates for Public Service, while GFCF data from 1984 to 1997 comes from the Annual Reports of Telecom Éireann (see Table 5.1).

Table 5.1: Data sources for telephone capital additions, 1922-1997

Source	Year	Notes
Dept. of Posts & Telegraphs	1923-80	Annual Reports: Commercial Accounts. Mainly found in Section 2, Table C under ‘Amounts Expended’
Dept. of Industry & Commerce	1931	Statistical Extracts: Commercial Accounts.
Estimates for Public Services	1981-83	Public Service Expenditure Annual Reports. Appendix of Vote 45: Posts and Telegraphs
Telecom Éireann	1984-98	Annual Reports: Group source and application of funds. Mainly found in Table 6 under ‘Tangible Fixed Assets’

Step two: Adjusting for price changes

To ensure the annual capital stock estimates for the entire period are meaningfully comparable we must construct indices of price changes for capital goods for the entire period. The capital assets in use at any one time are likely to have have been acquired over a number of preceding years (OECD, 2001b). The price of assets acquired in different years must be converted into constant year prices to value the capital stock consistently for the entire period (Keeney, 2007). Price indices for 1922 to 1948 are available from the Department of Industry and Commerce's Statistical Abstracts, while price indices for subsequent years are available from the Central Statistics Office's Statistical Abstracts (see Table 5.2). Price changes in the Statistical Abstracts were not compiled separately for capital goods until 1942 and even then the price data for non-transportable goods (buildings) and transportable goods (capital equipment) was not disaggregated until 1955. The methodology underlying the calculation of the wholesale price index numbers was changed in March 1955 (CSO, 1955 and 1957) and then changed again in 1978 in order to align the Irish series with other EEC member states (CSO, 1978 and 2009a). Further methodological changes to the wholesale price index series were introduced in 1989 and 1994. The price data has limitations, for example the data from 1976 to 1993 does not contain specific price changes for transportable capital goods for use in industry. Therefore for this period I use the overall price change for capital goods as a proxy for transportable capital good price changes. In order to convert the value of the capital additions for each year into the same unit I deflate the value of capital formation for each year from current year prices into constant 2000 prices.

Table 5.2: Data sources for capital good price indices, 1922-1997

Source	Year	Notes
Dept. of Industry and Commerce	1931-1949	First 18 editions of the Statistical Extracts: Information is usually contained in Section 10 – Prices; Cost of Living Data. Table number varies from year to year: e.g. Table 219, p.166 of 1931 edition and Table 238, p.195 of 1946 edition.
Central Statistics Office	1950-2001	Subsequent editions of the Statistical Extracts: Information is usually contained in Section 10, Section 13 or Section 15 – Prices; Table number varies: e.g. Table 253, p. 190-91 of 1950 edition and Tables 15.7 and 15.9, p.284-85 of 2001 edition.

Step three: Estimating capital depreciation

We obtain the Gross Fixed Capital Stock (GFCS) for each year of the dataset by adding together the inflation adjusted telephone capital additions. The GFCS is the total value, at market prices, of new assets of the same type held at a point in time by producers (OECD, 2001b). However, the Net Fixed Capital Stock (NFCS) for each year is of greater interest than the GFCS for the purposes of the current study because the NFCS accounts for the cumulative value of consumption (mainly depreciation) of fixed assets accrued up to that point (OECD, 2001b). According to United Nations Statistics (1993) the consumption of fixed assets is the decline in the current value of the stock of fixed assets due to deterioration, obsolescence and accidental damage. The total value of the NFCS of the telephone network at current market prices at the end of year *t* is expressed as:

$$C_t = (P_t)(I_t - D_t) \tag{5.1}$$

Where

C_t is the Net Fixed Capital Stock (NFCS) in IR£ at time t

P_t is the current market price in IR£ for new assets of the same type

I_t is the Gross Fixed Capital Stock (GFCS) in IR£ at time t

D_t is the cumulative value of Consumption of Fixed Capital in IR£ accrued by time t

To accurately estimate the NFCS we therefore need an approximation of the rate of consumption of fixed capital. There are a number of different ways to estimate the rate of consumption of fixed capital. The consumption of fixed capital is usually known as the depreciation function. H.R. Hudson and Russell Matthews (1963); Jorgenson (1974); Hofman (2000), and Keeney (2007) all provide theoretical overviews of different depreciation functions. The most commonly described depreciation functions are shown in Table 5.3.

Table 5.3: Capital depreciation functions – approximating the rate of consumption of fixed capital

Depreciation function	Year-on-year depreciation pattern
Constant age-efficiency profile	Asset value remains constant until the scrappage date
Straight-line pattern of depreciation	Asset value declines in equal proportions each year
Hyperbolic depreciation	Asset value declines hyperbolically – total depreciation rises each year
Declining balance (geometric) depreciation	Asset value declines geometrically – total depreciation falls each year

In order to obtain an accurate capital stock estimate we must use an appropriate depreciation function. The accuracy of the depreciation function relies on accurate estimates for the service lives of assets as well as estimates for the pattern of depreciation over the asset's lifespan. It seems unlikely that the annual level of depreciation will remain constant from year to year and equally unlikely that there will be no depreciation prior to the scrappage date. Based on an overview of the empirical literature the OECD (2001b) concludes that capital assets exhibit a very wide range of depreciation profiles. However, the most frequent depreciation profile in the empirical literature is a line which falls over time and displays convexity towards the origin. This profile is consistent with the declining balance (geometric) depreciation function. Geometric depreciation will never exhaust the full value of an asset. A pattern consistent with geometric depreciation was found to almost always hold for machinery and equipment, and to usually hold for buildings and other non-transportable assets. Following the conclusions of the OECD (2001b) and the BEA (2003) I use the geometric depreciation through this study.

The Irish state telecoms operator, Telecom Éireann, used an asset service life estimate of 40 years for buildings, and asset service life estimates ranging from 4 years to 20 years for machinery and equipment (Telecom Éireann, 1997). While there is no hard rule demanding that asset service lives must remain constant over time, an OECD (1993) study concluded there was little historical evidence of assets being used in production for shorter or longer periods. I use Telecom Éireann's assumed asset service life 'T' of 40 years for non-transportable assets, and I use an assumed asset service life of 10 years for transportable assets. Transportable and non-transportable assets will have substantially different rates of depreciation from each other because of their substantially different asset service lives. Empirical studies of second hand asset prices have generated estimates for the geometric or declining balance rate ‘R’ (OECD, 2001b). For example, the United States Government’s Bureau of Economic Analysis (BEA, 2003) undertook a wide ranging survey of capital goods encompassing the period 1925 to 1997 and found that the declining balance rate R was equal to 1.65 for machinery and equipment (transportable goods) and equal to 0.91 for residential structures (non-transportable goods). The BEA estimates for the declining balance rate R are used throughout this study. We can use a mortality function R/T to measure depreciation. Geometric depreciation in year *t* is obtained by multiplying the value of the asset in period *t-1* by the depreciation factor R/T. The value of the asset declines asymptotically. Depreciation in year *t* is expressed as follows:

$$D_t = (Q_{t-1})(R/T) \tag{5.2}$$

Where

D_t is the depreciation of the asset in year t

Q_{t-1} is the value of the asset in year $t-1$

R/T is the depreciation factor

T is the service life of the asset (as T increases the rate of depreciation will decrease)

R is the declining balance rate (as R increases so too will the rate of depreciation)

We therefore obtain the following depreciation function for transportable goods:

$$D_t = (\text{Value of Asset in period t-1}) \times (1.65/10) = .165(\text{Value of Asset in period t-1}) \tag{5.3}$$

The depreciation function for non-transportable goods is:

$$D_t = (\text{Value of Asset in period t-1}) \times (0.91/40) = .023(\text{Value of Asset in period t-1}) \tag{5.4}$$

The value of the asset will never reach zero prior to the scrappage date because the decline in value is asymptotic. As is evident from Equation 5.3 and Equation 5.4, the greatest amount of asset depreciation will occur in the first year, while the smallest amount of depreciation will occur in the final year before scrappage. I assume that transportable goods are scrapped in the eleventh year and that non-transportable goods are scrapped in the forty first year. The age-price profile of transportable assets is shown in Table 5.4 and the age-price profile of non-transportable assets is shown in Table 5.5. For example, by the seventh year 33.89 per cent of the value of transportable capital assets will remain while 86.97 per cent of the value of non-transportable capital assets will remain. These profiles are illustrated graphically in Figure 5.A and Figure 5.B.

Table 5.4: Geometric age price profile for transportable assets - remaining value (%)

Year	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**
1	100	4	58.22	7	33.89	10	19.73
2	83.5	5	48.61	8	28.3	11	**0**
3	69.72	6	40.59	9	23.63	**Total**	**506.19**

Table 5.5: Geometric age price profile for non-transportable assets – remaining value (%)

Year	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**
1	100	8	84.97	15	72.20	22	61.35	29	52.11	36	44.28
2	97.72	9	83.02	16	70.54	23	59.94	30	50.91	37	43.26
3	95.47	10	81.11	17	68.92	24	58.56	31	49.74	38	42.27
4	93.27	11	79.24	18	67.33	25	57.21	32	48.60	39	41.30
5	91.12	12	77.42	19	65.78	26	55.89	33	47.48	40	40.35
6	89.02	13	75.64	20	64.27	27	54.60	34	46.39	41	0
7	86.97	14	73.90	21	62.79	28	53.34	35	45.32	**Total**	**2633.6**

Step four: Constructing the capital stock estimates

To construct capital stock estimates for each year we begin with the initial telephone capital stock estimate for 1922 and then estimate the year-on-year change in the value of the telephone capital stock all of the way up to 1997. For each year the estimated value of the capital stock includes the composition of the capital stock by type (transportable and non-transportable), as well as the age distribution of the capital stock by vintage. To compile the dataset of capital stock estimates I add the value of new investment (gross fixed capital formation) for each year measured in constant 2000 prices and then subtract the value of capital assets lost to depreciation and scrappage during that same year. Total losses to depreciation and scrappage will vary each year depending on the age composition of the assets. When applying the geometric depreciation function newer assets will depreciate faster than older assets.

5.4 Ireland's Telephone Capital Stock: 1922 to 1997

Fixed telephone capital additions at current prices

The data sources for this section are outlined in Table 5.1. The full dataset for net capital additions expressed in current prices is presented in Table 5.6. Supplementary tables for capital additions are provided in the Appendix (see Table 5.A, Table 5.B, Table 5.C, Table 5.D and Table 5.E). The Department of Posts & Telegraphs figures for those capital additions made between 1922 and 1974 are for the fiscal year of April 1 to March 31. Annual totals were moved to a calendar year basis in 1974, and the 1974 figure shown in the dataset represents additions made between April 1 and December 31 of that year. Data for the period 1975 to 1983 is based on the calendar year of January 1 to December 31. The pre-1974 system was resumed in 1984. Due to this change the official data for 1984/85 reflects the period from January 1 1984 to March 31 1985. Data for 1985 through to 1997 reflects the fiscal year from April 1 to March 31. For consistency I assign all capital additions to the earlier year in every instance where the figures spill out over two calendar years. I do so because every instance of 'spillover' between two calendar years encompasses the nine months of April 1 to December 31 for the earlier year and encompasses just the remaining three months for the later year. For example the 1935/1936 capital additions are assigned to the year 1935 in the dataset.

All expenditure on 'telegraph' construction, a term that legally embraces the telephone network, was originally determined as a line item in the annual budget vote of the Dáil (Irish parliament). This followed the practice established by the British Post Office. Capital additions prior to 1959 were not disaggregated by type. For example land and buildings were not differentiated from engineering plant and stores. From 1959 onwards capital additions were disaggregated between telephone plant additions (transportable assets) and land and buildings (non-transportable assets). Telephone plant includes exchange equipment, underground cables and ducts, overhead wires and poles, telecommunication satellites, submarine cables and other equipment. By the early 1930s annual capital additions in current prices had fallen to less than a third of the level of annual additions in the late 1920s. Annual investment levels rose from £49,063 in 1931 to £261,462 in 1937 but then fell back to £54,199 by 1944. The annual net capital additions more than quadrupled in the year following World War II and overall the annual level of capital additions expressed in current prices increased twentyfold between 1941 and 1951. The level of annual capital additions stagnated again in the 1950s before increasing five-fold between 1957 and 1964. Growth of annual net capital additions was high throughout the 1970s although this apparent growth should be understood in the context of high underlying inflation rates.

The Estimates for Public Service for the years 1981, 1982 and 1983 only provide aggregate level data for capital investment in the telephone network. I was therefore forced to interpolate disaggregated values for transportable and non-transportable additions for this three year period. In doing so I assumed the composition of spending between the two categories of goods for these years was the same as for the average of the five years immediately preceding 1981, and the five years immediately following 1983. Based on that ten year dataset I obtain a breakdown for capital additions of 8.3 per cent spent on land and buildings and 91.7 per cent spent on telephone plant. Annual capital additions doubled between 1980 and 1981 and remained very high until late 1980s. Annual capital additions climbed again in the mid-1990s and reached a value of just under £300 million in 1997. The composition by type of asset was unavailable for 1995 and so I interpolated the breakdown of transportable and non-transportable goods, obtaining an estimated spending breakdown of 2.41 per cent on land and buildings and 97.59 per cent on telephone plant. The disaggregation of total capital additions between 1922 and 1958 into transportable versus non-transportable assets is also an estimate and was derived using the average composition of capital additions between 1959 and 1997. The composition between 1959 and 1997 is 93.22 per cent for transportable goods and 6.78 per cent for non-transportable goods. The compiled values for fixed capital additions at current prices are presented in Table 5.6.

Table 5.6: Annual net additions to telephone fixed capital in Ireland in current prices (IR£)

Year	Transportable Assets	Non-transportable Assets
1922	50,299	3,658
1923	23,650	1,720
1924	117,809	8,568
1925	191,784	13,949
1926	143,494	10,436
1927	118,978	8,653
1928	72,355	5,262
1929	90,155	6,557
1930	77,875	5,664
1931	45,737	3,326
1932	29,541	2,149
1933	28,629	2,082
1934	46,666	3,394
1935	78,751	5,728
1936	109,476	7,962
1937	243,735	17,727
1938	242,707	17,652
1939	141,151	10,266
1940	178,260	12,965
1941	107,787	7,840
1942	65,379	4,755
1943	74,794	5,440
1944	50,524	3,675
1945	87,437	6,359
1946	355,186	25,833
1947	409,749	29,801
1948	1,013,681	73,726
1949	1,265,309	92,027
1950	1,709,826	124,358
1951	2,222,379	161,636
1952	1,784,072	129,785
1953	1,005,151	73,106
1954	1,480,134	107,652
1955	1,542,511	112,887
1956	1,516,768	110,316
1957	1,125,162	81,834
1958	1,321,754	96,133
1959	1,568,455	134,885
1960	2,162,677	109,177
1961	2,290,351	101,686
1962	3,256,255	257,811
1963	4,004,004	360,910
1964	5,519,224	521,821
1965	5,541,991	839,904
1966	5,372,100	460,781
1967	5,884,533	503,756
1968	6,299,101	413,641
1969	7,384,971	533,856
1970	9,018,800	563,428
1971	10,361,406	857,435
1972	16,273,376	1,339,935
1973	21,846,174	1,342,453
1974	22,080,005	1,588,176
1975	39,827,116	2,754,059

Sources: Dept. of Posts and Telegraphs (1923-1981); Estimates for Public Service Annual Reports (1981-1983); Telecom Éireann Annual Reports (1985-1998); Author’s calculations. Table continues on the next page.

Table 5.6 (cont.): Annual net additions to telephone fixed capital in Ireland in current prices (IR£)

Year	Transportable Assets	Non-transportable Assets
1976	41,778,418	3,126,537
1977	43,178,843	5,044,227
1978	53,164,926	7,177,419
1979	60,764,217	11,680,909
1980	96,680,540	29,973,671
1981	201,740,000	18,260,000
1982	218,246,000	19,754,000
1983	223,748,000	20,252,000
1984	207,797,000	12,131,000
1985	126,184,000	3,037,000
1986	137,184,000	1,222,000
1987	121,291,000	1,003,000
1988	108,301,000	4,941,000
1989	143,847,000	7,076,000
1990	151,963,000	22,809,000
1991	142,059,000	8,334,000
1992	156,886,000	2,555,000
1993	160,742,000	2,929,000
1994	167,855,000	4,145,000
1995	196,043,000	1,910,000
1996	261,618,000	6,812,000
1997	290,542,000	5,987,000

Sources: See Table 5.1; Department of Posts and Telegraphs (1923 to 1981); Estimates for Public Service Annual Reports (1981 to 1983); Telecom Éireann Annual Reports (1985 to 1998); Author's calculations

Capital goods price indices

The data sources for price levels are shown in Table 5.2. Price level data is available from the historical series of Statistical Abstracts of Ireland which have been published annually since 1931. The abstracts were compiled by the Department of Industry and Commerce until 1949 and by the Central Statistics Office ever since. The capital goods price indices for 1922 to 2000 are shown in Table 5.7 while additional price indices are presented in the Appendix (see Table 5.F, Table G, Table 5.H, Table 5.I, Table 5.J and Table 5.K).

Price changes were not compiled separately for capital goods until 1942 so instead I use the index numbers for the cost of living as these provide the closest available estimate for capital goods price changes. Prices declined overall by 6.5 per cent between independence in 1922 and the outbreak of World War II in 1939. The main cause of the price deflation was weak underlying demand in the economy. Deflation was particularly sharp during the height of the Great Depression. Prices fell by 6.5 per cent in 1931 alone and by over 14 per cent in total between 1929 and 1933. On the other hand the supply of goods and services was severely constrained during the Emergency leading to an increase of over 70 per cent in the cost of living between 1939 and 1945. Inflation rose to 19.1 per cent in 1940. The Department of Industry and Commerce began publishing data for capital good prices from 1942. However, the price indices were not disaggregated into capital equipment and building materials and there was no distinction made in the abstracts between transportable and non-transportable goods until 1954. The 1955 Statistical Abstract reported price data for buildings and capital equipment separately for the first time (CSO Statistical Abstract, 1955). A new series of wholesale price index numbers was introduced in 1955 as the Laspeyres index price formula was replaced by the Fisher “Ideal” price formula (CSO Statistical Abstract, 1957). Prices grew at a faster rate for buildings and construction goods than they did for machinery and equipment (transportable goods). Prices rose by an average of 2.1 per cent per annum between 1953 and 1960, by an average of 4.7 per cent per annum between 1960 and 1970, and by an average of 15.8 per cent per annum between 1970 and 1975. The price level data reported by the Statistical Abstracts for the period 1976 to 1993 no longer included price changes for transportable capital goods for use in industry. Instead I use the overall price change for capital goods as a proxy indicator of non-building capital good price changes for the 1976 to 1993 period. I estimate capital goods prices increased by an average of 11.7 per cent per annum over this period. The CSO reverted to its pre 1976 practice of measuring price changes for ‘transportable capital goods for use in industry’ starting with the 1994 price index. I estimate that capital goods prices increased by an average of 2.6 per cent per annum from 1993 to 2000.

Taking 1914 as the base year, in Table 5.7 I report the index of price changes for capital goods between 1922 and 2000. This was the base year for the earliest price estimates in the *Statistical Abstracts*. Thus if a basket of goods cost £100 in 1914; the exact same basket of goods is estimated to cost £360.36 in 1950. The price changes from 1922 to 1941 reflect the cost of living index, price changes from 1942 to 1953 reflect price changes for capital equipment, and price changes from 1954 to 1975 reflect disaggregated data for transportable goods and for buildings. The 1920s was a period of mild deflation while every other decade was characterised by price inflation of various degrees. The 1970s had by far the largest decade-on-decade increases in prices. The 1980s and the 1940s had the next highest levels of price inflation. The 1950s, 1960s and 1990s were characterised by stable and relatively low price inflation. Although prices increased overall in the 1930s the decade experienced wild swings of inflation and deflation. Overall the average rate of inflation for building and construction goods over the period 1953 and 2000 was approximately twice the average rate of inflation for transportable capital goods.

Table 5.7: Capital goods price indices, 1922 to 2000 (Base series 1914 = 100)

Year	Transportable goods	Ten Year Price Change (%)	Building & Construction	Ten Year Price Change (%)
1922	185	-	185	-
1930	168	-9.2	168	-9.2
1940	206	22.6	206	22.6
1950	360.36	74.9	360.36	74.9
1960	494.27	37.2	496	37.6
1970	646.32	30.8	846.02	70.6
1980	2222.39	343.9	3883.33	459
1990	3965.37	78.4	7031.43	81.1
2000	4800.70	21.1	9739.40	38.5

Sources: See Table 5.2; Department of Industry and Commerce (1931 to 1948); CSO Statistical Abstracts of Ireland (1949 to 2001)

Price changes from 1922 to 1953 are shown in Figure 5.1., while Figure 5.2 and Figure 5.3 show price changes for transportable capital goods and non-transportable capital goods respectively from 1954 to 2000.

Figure 5.1: Price levels (all goods and services) from 1922 to 1953 in IR£ (Base 1914 = £100)

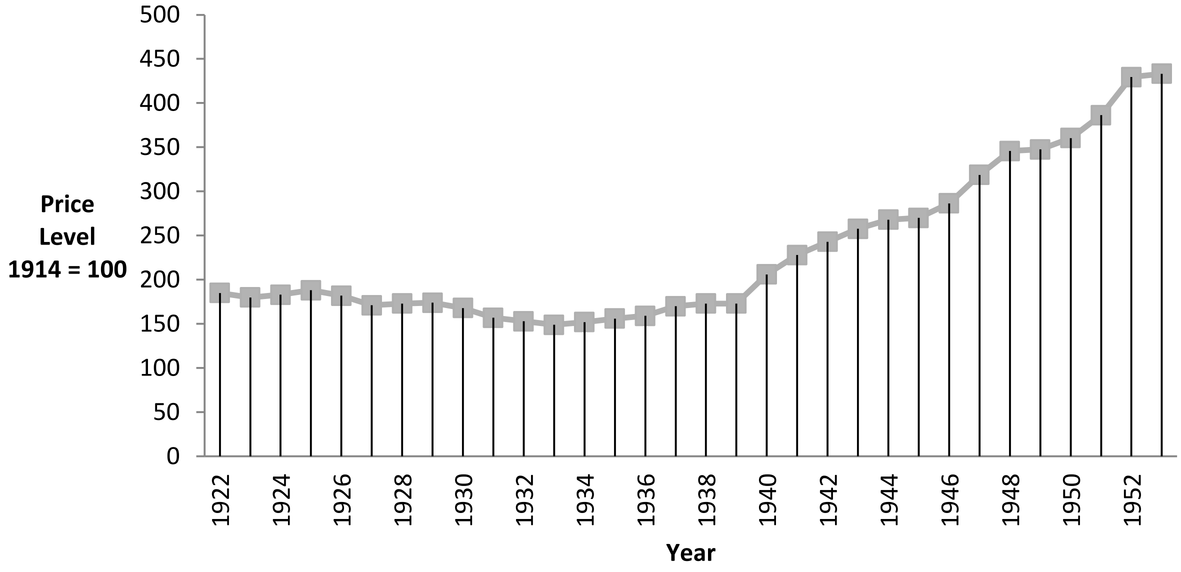


Figure 5.2: Price levels for transportable capital goods 1954 to 2000 in IR£ (Base 1914 = £100)

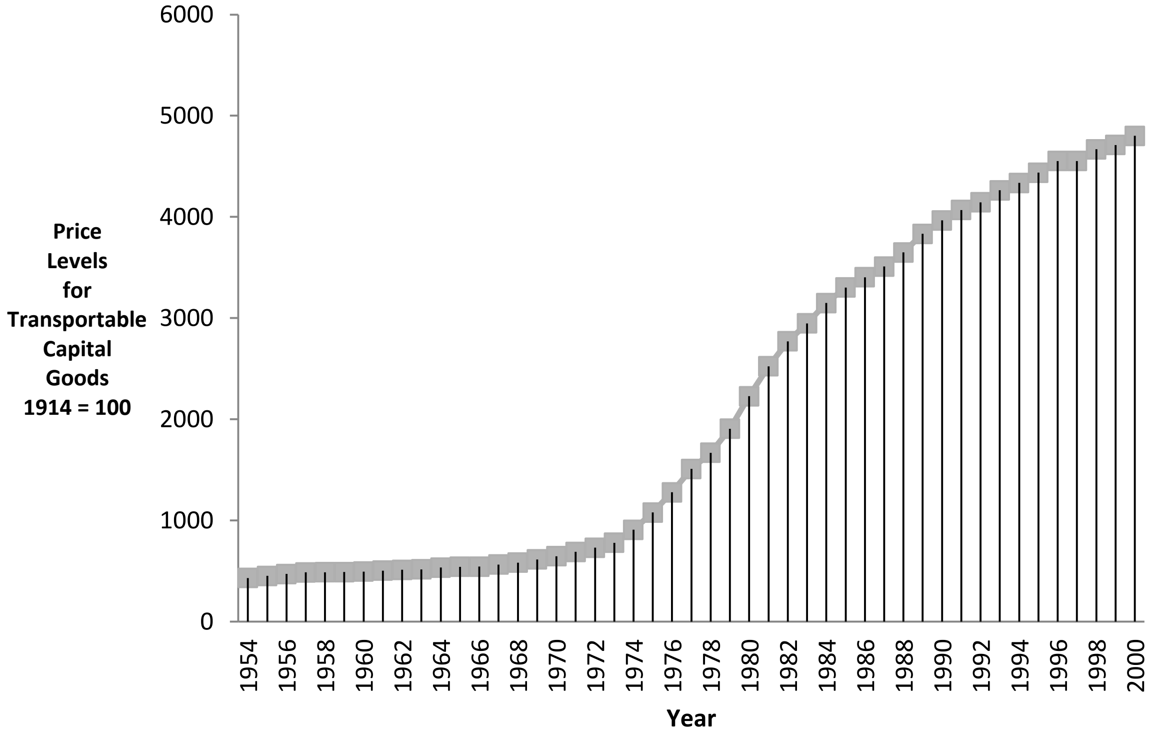
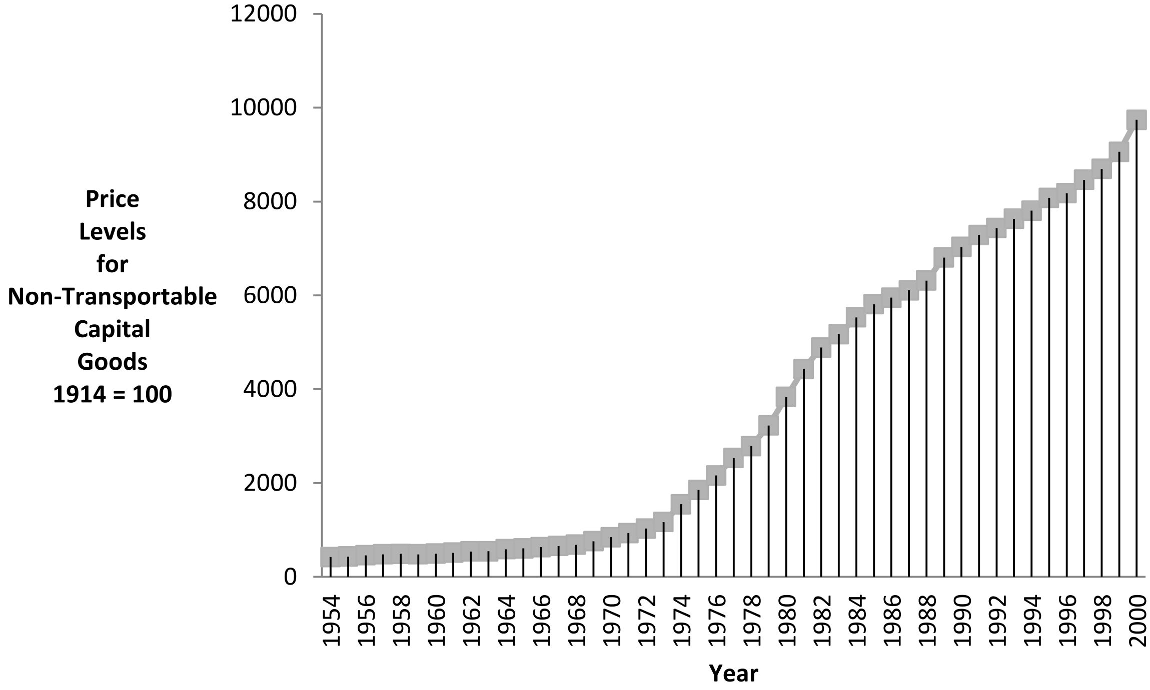


Figure 5.3: Price levels for non-transportable capital goods 1954 to 2000 in IR£ (Base 1914 = £100)



Fixed telephone capital additions measured in constant 2000 prices

In Table 5.8 I present the ratios used to convert the current price data to constant 2000 prices. The conversion ratio is derived from the price indices and is used to transform the value of the capital additions from current year prices to constant 2000 prices. The conversion ratio is:

$$\text{Conversion ratio for year t capital additions} = (P_{2000})/(P_t) \qquad (5.5)$$

Where

P_{2000} is the price index for year 2000 and

P_t is the price index for year t.

Table 5.8: Ratio of conversion from current year prices to constant 2000 prices, 1922 to 2000

Year	Transportable goods	Building & Construction
1922	25.9457	52.6454
1930	28.5756	57.9726
1940	23.3044	47.2786
1950	13.3220	27.0269
1960	9.7127	19.6359
1970	7.4277	11.5120
1980	2.1553	2.5080
1990	1.2107	1.3851
2000	1.0000	1.0000

Note: Base series 2000 = 1

Source: Author’s calculations

The annual fixed capital additions measured in constant 2000 prices are presented in Table 5.9.

Table 5.9: Annual net additions to fixed telephone capital in constant 2000 prices (IR£)

Year	Transportable assets	Non-transportable assets
1922	1,305,244	192,577
1923	710,771	93,065
1924	3,090,519	455,996
1925	4,897,320	722,632
1926	3,785,013	558,464
1927	3,340,224	492,837
1928	2,007,830	296,237
1929	2,487,394	367,019
1930	2,225,325	328,357
1931	1,398,532	206,326
1932	926,911	136,797
1933	922,412	136,090
1934	1,473,880	217,471
1935	2,423,460	357,611
1936	3,305,420	487,705
1937	6,882,930	1,015,590
1938	6,735,046	993,756
1939	3,916,898	577,946
1940	4,154,242	612,967
1941	2,269,531	334,899
1942	1,292,209	190,666
1943	1,393,883	205,677
1944	905,107	133,563
1945	1,554,376	229,339
1946	5,951,852	878,208
1947	6,172,787	910,799
1948	14,078,914	2,077,385
1949	17,477,207	2,578,799
1950	22,778,302	3,361,011
1951	27,617,726	4,075,070
1952	19,956,460	2,943,770
1953	11,139,284	1,643,642
1954	16,469,007	2,472,271
1955	16,389,488	2,530,441
1956	15,449,647	2,324,513
1957	11,083,746	1,650,101
1958	12,974,337	1,904,279
1959	15,341,686	2,724,731
1960	21,005,433	2,143,789

Sources: See Table 5.1 and Table 5.2; Department of Posts & Telegraphs (1923 to 1981); Estimates for Public Service (1981 to 1983); Telecom Éireann (1985 to 1998); Department of Industry and Commerce (1931 to 1949) Central Statistics Office (1949 to 2000). Table continues on the next page

Table 5.9 (cont.): Annual net additions to fixed telephone capital in constant 2000 prices (IR£)

Year	Transportable assets	Non-transportable assets
1961	21,787,193	1,919,567
1962	30,529,996	4,622,293
1963	37,194,357	6,433,690
1964	49,647,076	8,613,960
1965	49,056,042	13,459,294
1966	46,511,642	7,066,630
1967	50,048,542	7,446,269
1968	51,786,169	5,867,415
1969	57,594,650	6,835,225
1970	66,988,940	6,486,183
1971	72,127,819	8,933,187
1972	106,729,896	12,647,244
1973	134,426,063	11,166,256
1974	116,743,610	13,169,949
1975	177,258,545	14,470,652
1976	156,915,560	14,088,801
1977	137,364,853	19,387,991
1978	152,854,479	25,057,805
1979	152,967,840	35,252,983
1980	208,375,568	75,173,967
1981	383,709,480	40,142,784
1982	378,242,214	39,359,845
1983	364,373,618	38,126,415
1984	316,828,086	21,352,986
1985	183,471,536	5,090,012
1986	193,470,595	2,000,047
1987	165,901,830	1,599,484
1988	142,502,456	7,618,528
1989	180,153,983	10,127,879
1990	183,888,380	31,592,746
1991	167,658,032	11,138,391
1992	181,768,120	3,348,072
1993	181,043,715	3,738,869
1994	185,882,627	5,172,960
1995	212,079,317	2,303,780
1996	279,277,215	8,114,454
1997	306,347,485	6,891,636

Sources: See Table 5.1 and Table 5.2; Department of Posts & Telegraphs (1923 to 1981); Estimates for Public Service (1981 to 1983); Telecom Eireann (1985 to 1998); Department of Industry and Commerce (1931 to 1949) Central Statistics Office (1949 to 2000)

Figure 5.4 and Figure 5.5 show the annual additions to transportable and non-transportable assets measured in constant 2000 prices. Although the general trend is upwards there are a number of exceptions. There were low levels of investment in the years immediately following independence as the new state was stabilizing after the Civil War. I estimate the lowest level of fixed capital investment in the network occurred in 1923 while the early 1930s and the early 1940s were characterised by declining investment. Both of these periods of decline were followed by short periods of rapid expansion. The boom in investment of the late 1940s gave away to stagnation in the 1950s although growth in investment was to resume in the 1960s. The highest annual levels of fixed capital investment occurred during the early 1980s. The level of net telephone capital additions peaked at over £423 million in 1981.

Figure 5.4: Annual addition to transportable capital in millions (IR£), constant 2000 prices, 1922-97

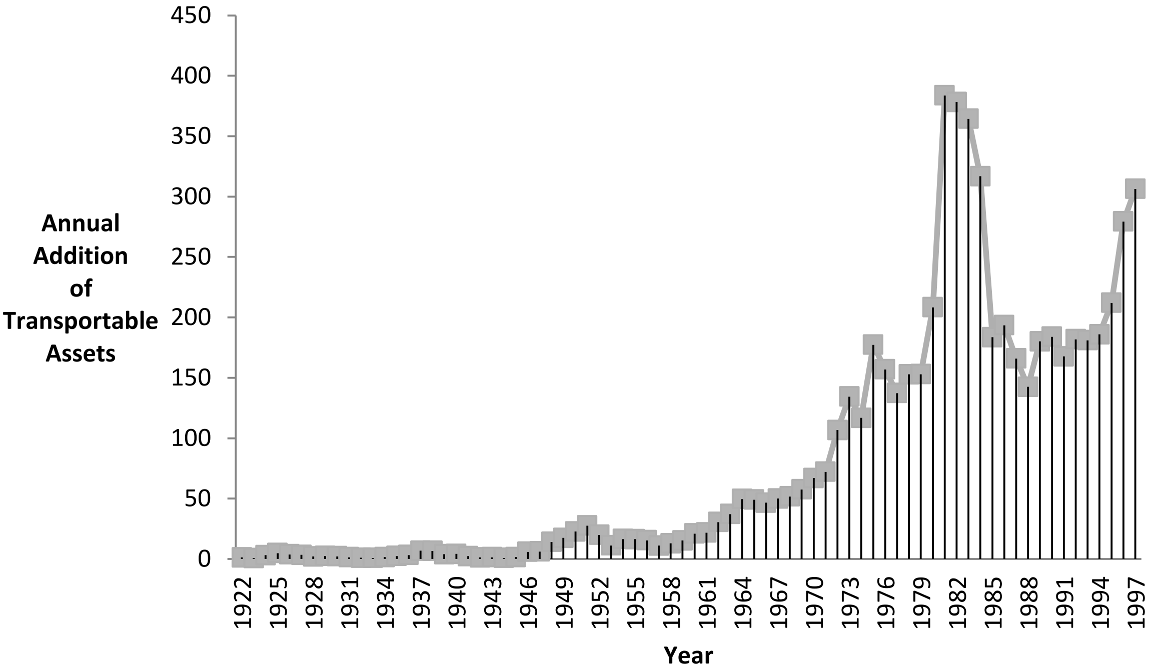
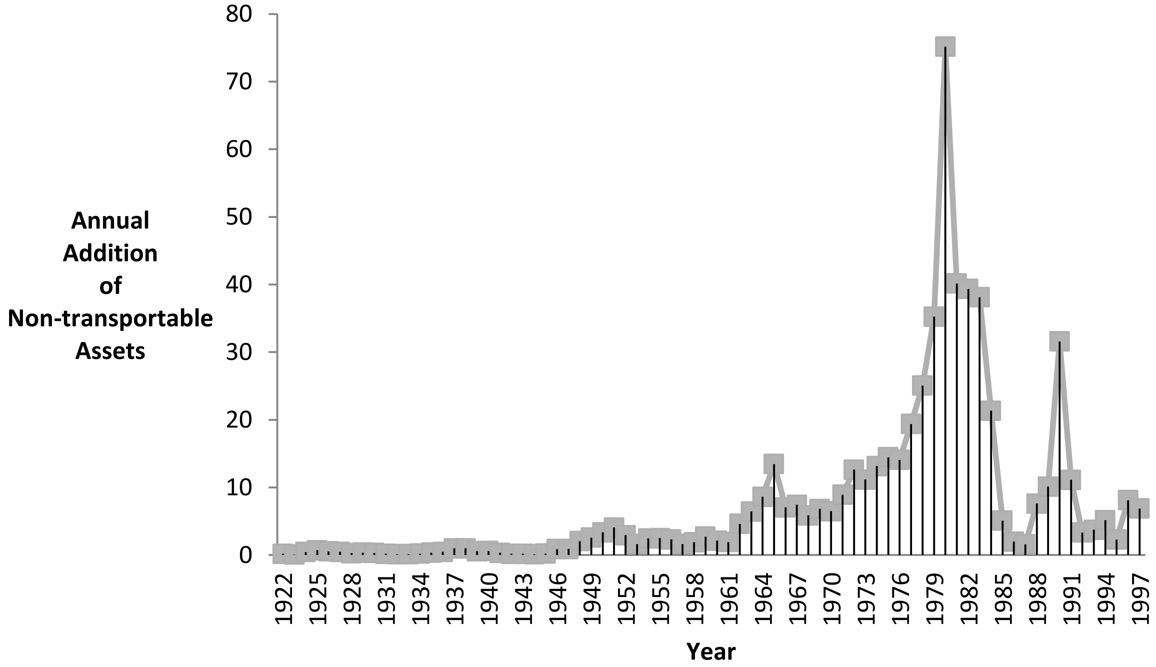


Figure 5.5: Annual addition to non-transportable assets in millions (IR£), constant 2000 prices, 1922-97



Baseline capital stock estimate for the starting year

The pre 1922 fixed capital stock is estimated at £778,858 in current prices (see Table 5.A). The fixed capital stock will have been composed of forty different years' worth of non-transportable capital additions as well as ten different years' worth of transportable capital additions. Forty years of capital additions is reasonable as the network had been in existence in one form or another since the United Telephone Company opened the first exchange in Ireland in 1880. For simplicity I assume the composition of capital additions for each year is broadly similar to the average composition of capital additions in the post-independence period. That composition is 93.22 per cent transportable goods and 6.78 per cent non-transportable goods. I assume for convenience that the annual levels of pre-1922 additions are constant for each year. From the geometric age price profiles presented in Table 5.4 and Table 5.5 we can derive the composition of the pre 1922 capital stock as follows where x represents annual additions of transportable assets and y represents annual additions of non-transportable assets:

$$x(5.0619) + y(26.336) = \pounds 778{,}858 \qquad (5.6)$$

If the pre-1922 composition of capital additions is the same as the composition for the post-independence period we get:

$$x = y(93.22/6.78) = 13.75y \tag{5.7}$$

Which gives x equal to £111,628 and y equal to £8,118. On this basis I estimate that the annual net additions of transportable assets prior to 1922 were £111,628, while annual net additions of non-transportable assets prior to 1922 were £8,118. From Equation 5.6 I estimate the stock of transportable assets was worth approximately £565,050 in 1922 while the estimated stock of non-transportable assets was worth approximately £213,796 in 1922. The derived age distribution for the remaining stock of telephone capital at the time of independence is shown in the Appendix in Table 5.L (transportable assets) and Table 5.M (non-transportable assets) and is expressed in constant 2000 prices. The total capital stock prior to Independence is estimated at £25,920,198 in constant 2000 prices. The stock of transportable assets just prior to Independence is estimated at £14,662,887 and the stock of non-transportable assets is estimated at £11,257, 271.

Capital stock estimates for the Irish telephone network in constant 2000 prices

I estimate the telephone capital stock to have declined between 1921 and 1934. The capital stock declined to its lowest level of just over £19 million in 1934 and remained below its pre-independence level until 1938. The capital stock fell below pre-independence levels again in 1944 and 1945 and only finally exceeded pre-independence levels permanently in 1946. Annual levels of investment accelerated in the post-war period and I estimate the value of the capital stock to have doubled between 1945 and 1948 and to have increased five-fold between 1945 and 1952. Capital stock levels stalled between 1952 and 1960 but began to rise again in the 1960s. The capital stock doubled between 1959 and 1965 and then doubled again between 1965 and 1972. According to the estimates, the capital stock, measured in constant 2000 prices, peaked at over £1.8 billion in 1984. I estimate the telephone network's capital stock in 1997 at £1.5 billion. This was equivalent to over £400 per person resident in the state. By way of comparison I estimate the telephone network's capital stock at £8.56 per person in 1921/22.

Table 5.10 shows an extract from the disaggregated capital stock tables expressed in constant 2000 prices. The extract shown is for the transportable capital stock and shows the changing transportable capital stock throughout the 1940s decomposed by the year the additions were originally made (the vintage). The data in Table 5.10 requires some explanation. The underlined value in the column for 1940 tells us that net capital additions in 1940 were worth £4,154,242 (see Table 5.9). The underlined values for the nine years from 1941 to 1949 show the remaining ‘non-depreciated’ value of the 1940 capital additions. With a service life of ten years the residual value of transportable assets added in 1940 falls to zero in 1950 due to scrappage. The values in bold in Table 5.10 show the total values of the transportable capital stock for the year in question. Thus the transportable capital stock is £19,973,715 in 1940 and £55,759,839 in 1950. I also show the capital stock decomposed by vintage. For example, turning again to the 1940 capital stock we can see the most recent vintage is valued at £4,154,242, the second most recent vintage is valued at £3,270,610, and the oldest vintage is valued at £275,930. The estimated capital stock of the Irish telephone network is presented in Table 5.11 and is illustrated in Figure 5.6, Figure 5.7 and Figure 5.8.

Table 5.10: Extract from decomposed capital stock tables, transportable assets, constant 2000 prices (IR£)

1940	**1941**	**1942**	**1943**	**1944**	**1945**	**1946**	**1947**	**1948**	**1949**	**1950**
275,930										
219,029	182,880									
261,043	217,966	181,992								
499,498	417,108	348,278	290,797							
983,682	821,311	685,839	572,664	478,149						
1,606,765	1,341,670	1,120,207	935,434	781,071	652,159					
4,007,242	3,345,792	2,793,781	2,332,625	1,947,869	1,626,436	1,358,002				
4,695,674	3,921,144	3,273,906	2,733,755	2,282,507	1,906,018	1,591,491	1,328,825			
3,270,610	2,730,861	2,280,418	1,904,004	1,589,869	1,327,437	1,108,482	925,563	772,804		
4,154,242	*3,468,792*	*2,896,338*	*2,418,600*	*2,019,377*	*1,686,207*	*1,407,873*	*1,175,650*	*981,647*	*819,632*	
19,973,715	2,269,531	1,895,058	1,582,317	1,321,321	1,103,219	921,203	769,144	642,277	536,290	447,778
	18,717,055	1,292,209	1,078,995	900,928	752,324	628,143	524,508	437,930	365,695	305,349
		16,768,026	1,393,883	1,163,892	971,815	811,519	677,567	565,777	472,387	394,469
			15,243,074	905,107	755,764	631,041	526,953	439,973	367,383	306,741
				13,390,090	1,554,376	1,298,250	1,083,711	904,958	755,582	630,921
					12,335,755	5,951,852	4,969,796	4,149,631	3,465,168	2,893,195
						15,707,856	6,172,787	5,154,277	4,303,667	3,593,797
							18,154,504	14,078,914	11,755,893	9,815,819
								28,128,188	17,477,207	14,593,468
									40,318,904	22,778,302
										55,759,839

Table 5.11: Telephone capital stock estimates expressed in constant 2000 prices (IR£), 1921 to 1997

Year	**Machinery & Equipment**	**Buildings & Land**	**Total**
1921	14,662,887	11,257,271	25,920,158
1922	13,071,415	11,020,552	24,091,967
1923	11,148,063	10,691,595	21,839,658
1924	11,921,852	10,733,121	22,654,973
1925	14,374,421	11,040,413	25,414,834
1926	15,310,536	11,176,529	26,487,065
1927	15,647,211	11,253,848	26,901,059
1928	14,595,985	11,112,991	25,708,976
1929	14,197,680	11,055,956	25,253,636
1930	13,603,029	11,051,482	24,654,511
1931	12,279,667	10,747,065	23,026,732
1932	10,965,354	10,468,152	21,433,506
1933	9,961,281	10,194,953	20,156,234
1934	9,282,301	10,009,400	19,291,701
1935	9,367,261	9,968,274	19,335,535
1936	10,503,433	10,058,233	20,561,666
1937	15,102,947	10,674,037	25,776,984
1938	19,015,512	11,253,951	30,269,463
1939	19,384,599	11,404,642	30,789,241
1940	19,973,715	11,586,812	31,560,527
1941	18,717,055	11,486,690	30,203,745
1942	16,768,026	11,244,559	28,012,585
1943	15,243,074	11,023,004	26,266,078
1944	13,390,090	10,734,461	24,124,551
1945	12,355,075	10,548,291	22,903,366
1946	15,707,856	11,015,502	26,723,358
1947	18,154,054	11,504,576	29,658,630
1948	28,128,188	13,148,999	41,277,187
1949	40,318,904	15,257,218	55,576,122
1950	55,759,839	18,099,169	73,859,008
1951	73,803,160	21,589,877	95,393,037
1952	81,368,668	23,869,013	105,237,681
1953	78,852,036	24,795,253	103,647,289
1954	82,160,868	26,528,478	108,689,346
1955	84,737,170	28,279,531	113,016,701
1956	85,233,577	29,785,824	115,019,401
1957	81,228,011	30,582,458	111,810,469
1958	78,479,409	31,614,859	110,094,268
1959	77,992,338	33,444,075	111,436,413
1960	82,375,217	34,650,721	117,025,938

Table continues on the next page.

Table 5.11 (cont.): Telephone capital stock estimates expressed in constant 2000 prices (IR£), 1921 to 1997

Year	**Machinery & Equipment**	**Buildings & Land**	**Total**
1961	86,020,192	35,593,772	121,613,964
1962	99,068,455	39,308,108	138,376,563
1963	118,079,878	44,836,774	162,916,652
1964	145,530,413	52,242,180	197,772,613
1965	167,873,018	64,215,111	232,088,129
1966	184,138,754	69,577,589	253,716,343
1967	201,977,924	75,226,599	277,204,523
1968	218,298,572	79,244,707	297,543,279
1969	237,343,479	84,073,830	321,417,309
1970	260,909,255	88,536,562	349,445,817
1971	287,063,964	95,352,131	382,416,095
1972	341,396,324	105,753,072	447,149,396
1973	413,362,324	114,434,865	527,797,189
1974	453,748,792	124,899,105	578,647,897
1975	488,029,429	131,176,697	619,206,126
1976	606,854,515	146,795,247	753,649,762
1977	635,837,323	162,648,403	798,485,726
1978	675,244,039	183,646,551	890,948,782
1979	707,302,231	214,450,111	921,752,342
1980	787,931,649	284,453,664	1,072,385,313
1981	1,029,743,266	317,918,561	1,347,661,827
1982	1,226,487,536	349,907,665	1,576,395,201
1983	1,371,296,072	379,896,476	1,751,192,548
1984	1,434,296,092	392,458,211	1,826,754,303
1985	1,351,895,087	388,427,827	1,740,322,914
1986	1,296,441,261	381,147,565	1,677,588,826
1987	1,226,787,794	373,612,549	1,600,400,343
1988	1,240,840,467	371,817,184	1,612,657,651
1989	1,107,596,720	372,375,334	1,479,972,054
1990	1,075,125,152	394,077,256	1,469,202,408
1991	1,021,517,238	394,551,110	1,416,068,348
1992	958,730,068	387,659,428	1,346,389,496
1993	919,026,501	381,765,004	1,346,389,950
1994	900,966,348	377,248,208	1,278,214,556
1995	934,235,981	369,874,305	1,304,110,286
1996	1,027,483,452	368,566,177	1,396,049,629
1997	1,136,957,395	366,349,985	1,503,307,380

Figure 5.6: Transportable telephone capital stock in millions (IR£), constant 2000 prices, 1921-97

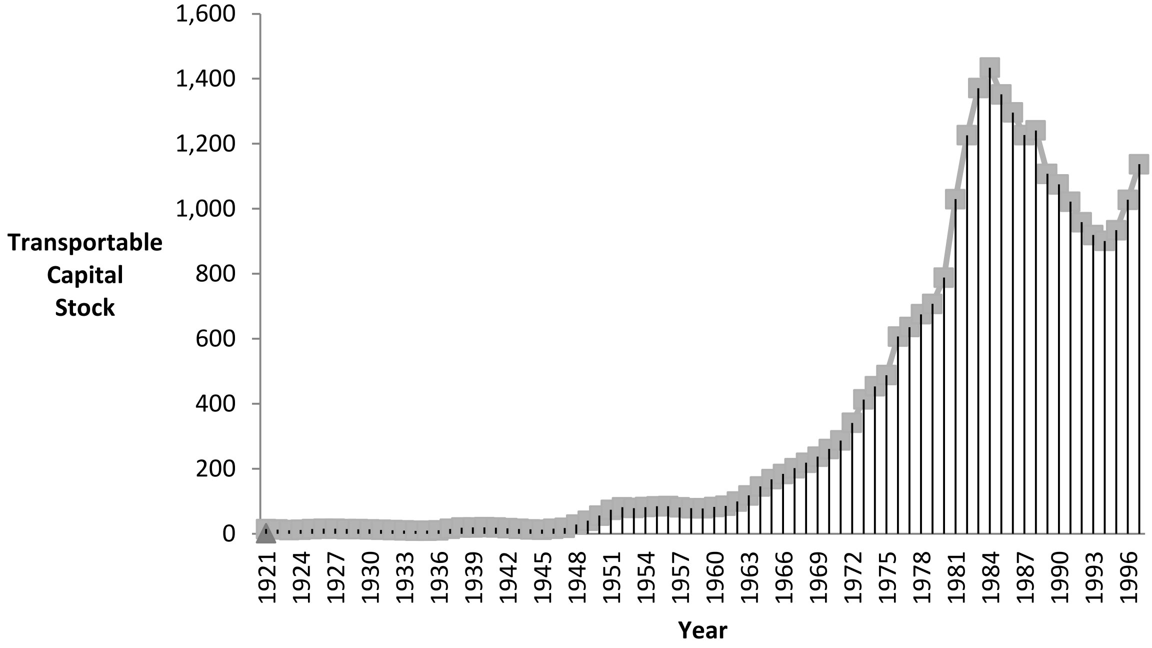


Figure 5.7: Non-transportable telephone capital stock in millions (IR£), constant 2000 prices, 1921-97

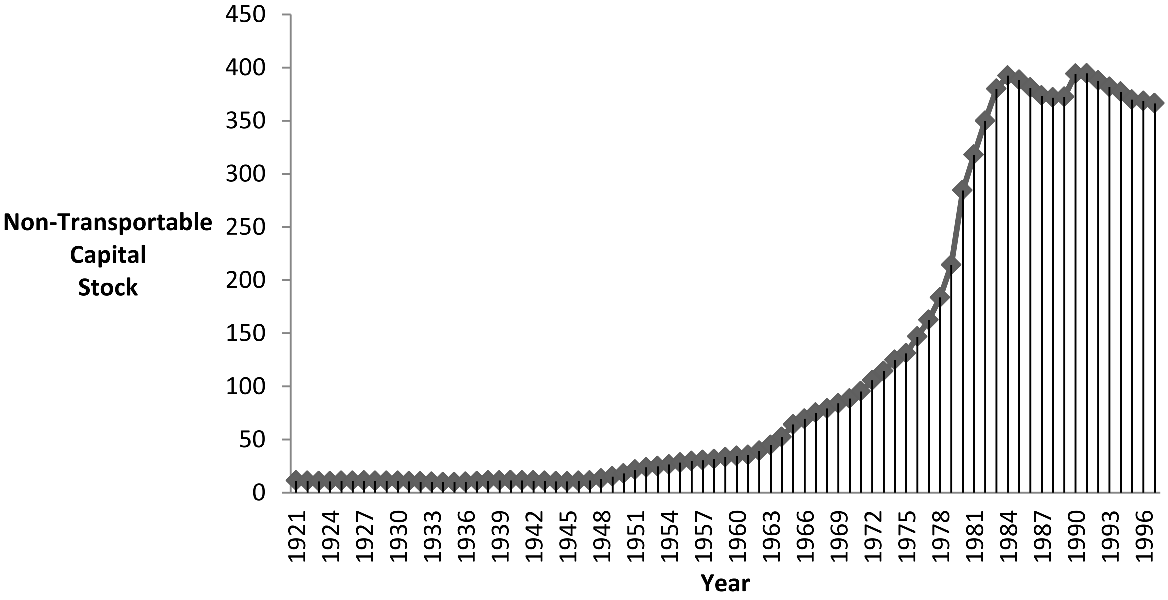
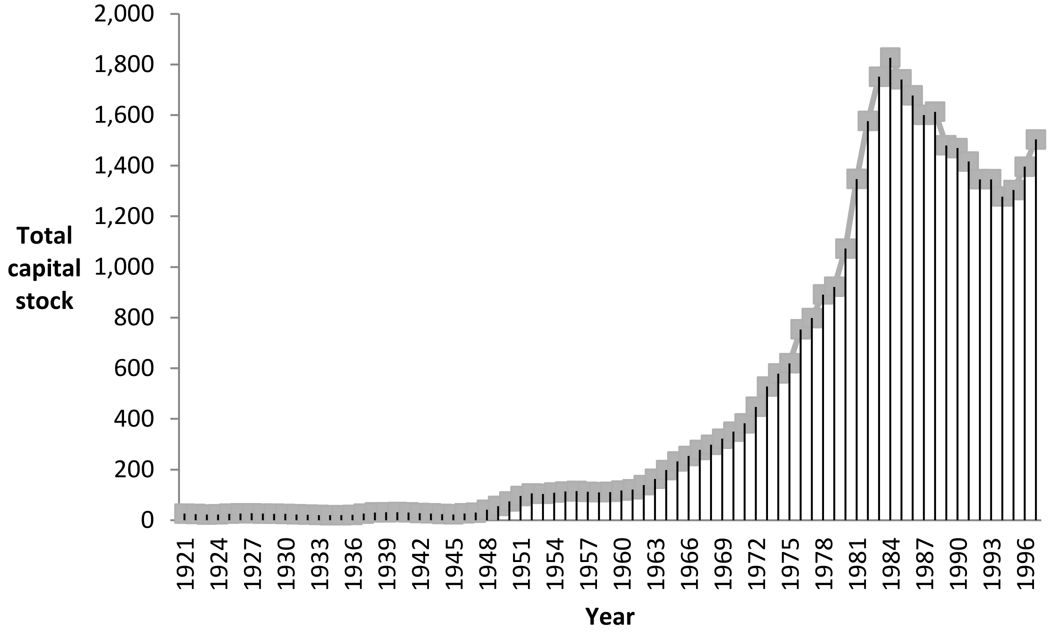


Figure 5.8: Total capital stock of the Irish telephone network in millions (IR£), constant 2000 prices, 1921-97



The per capita capital stock

The Irish state's population was in slow decline for most of the first forty years of the State's existence CSO (2009b). The population started to increase slowly from the 1960s onwards and by 1972/73 the population level had increased sufficiently to match the population level at Independence. By 1997 the population had increased to 3.7 million. I estimate the per capita telephone capital stock in 1921 at £8.56 (see Table 5.12). This level subsequently declined, reaching a low of £6.50 in 1934. The per capita telephone capital stock did not exceed pre-independence levels until 1937 and would not permanently exceed £10 per person until 1947. Following a period of substantial investment between 1948 and 1952 the per capita value ranged between £30 and £40 during the 1950s. The per capita value of the capital stock began to steadily increase in the 1960s and finally surpassed £100 for the first time in 1968. By 1980 the per capita value of the capital stock was in excess of £300, and by 1983 was in excess of £500. The per capita stock peaked at £526.73 in 1984. I estimate the per capita stock to have been £409.11 in 1997. This is illustrated in Figure 5.9.

Table 5.12: Per capita telephone capital stock 1921 to 1997 at constant 2000 prices (IR£)

Year	**Per Capita Telephone Capital Stock**
1921	8.56
1922	7.99
1923	7.27
1924	7.57
1925	8.52
1926	8.91
1927	9.05
1928	8.65
1929	8.50
1930	8.30
1931	7.75
1932	7.22
1933	6.79
1934	6.50
1935	6.51
1936	6.93
1937	8.69
1938	10.21
1939	10.39
1940	10.65
1941	10.20
1942	9.46
1943	8.88
1944	8.16
1945	7.75
1946	9.04
1947	10.03
1948	13.96
1949	18.79
1950	24.96
1951	32.22
1952	35.72
1953	35.35
1954	37.25
1955	38.92
1956	39.81
1957	38.89
1958	38.48
1959	39.14
1960	41.31

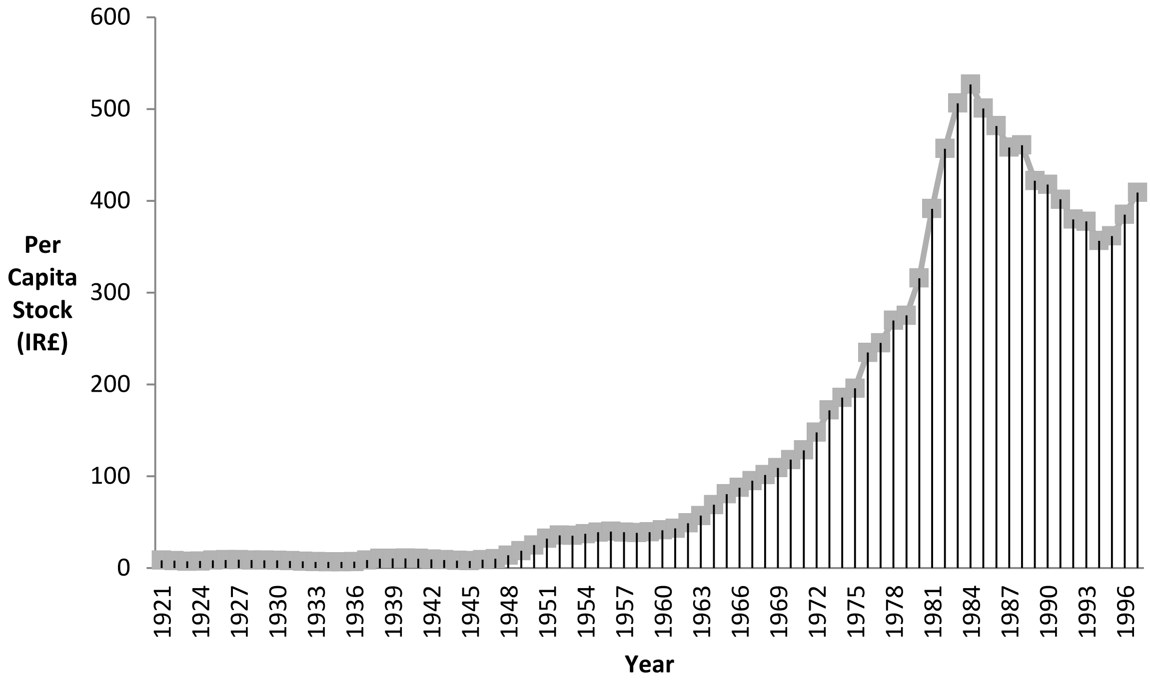
Sources: CSO (2009b); Author's calculations. Table continues on the next page.

Table 5.12 (cont.): Per capita telephone capital stock 1921 to 1997 at constant 2000 prices (IR£)

Year	Per Capita Telephone Capital Stock
1961	43.15
1962	48.82
1963	57.16
1964	69.00
1965	80.52
1966	87.54
1967	95.12
1968	101.54
1969	109.09
1970	117.97
1971	128.40
1972	147.83
1973	171.85
1974	185.60
1975	195.68
1976	234.72
1977	245.13
1978	269.67
1979	275.12
1980	315.70
1981	391.37
1982	456.71
1983	506.14
1984	526.73
1985	500.62
1986	481.43
1987	458.20
1988	460.62
1989	421.73
1990	417.69
1991	401.64
1992	379.71
1993	377.58
1994	356.45
1995	361.65
1996	385.00
1997	409.11

Sources: CSO (2009b); Author’s calculations

Figure 5.9: Per capita telephone capital stock in Ireland, constant 2000 prices (IR£), 1921-97



5.5 Conclusion

The Irish state inherited a small and outdated telephone network. I estimate that the value of the network's capital stock at that time was worth approximately £25.9 million in 2000 prices. Investment in the network was 'stop-go' during the twentieth century with two separate periods of large-scale increases in annual capital additions. How can we interpret these findings? The evidence suggests that the telephone network infrastructure was not a government priority, particularly before the mid-1940s. The quality of the network continued to remain poor until the early 1980s. Due to a sustained period of investment the per capita capital stock more than doubled between 1977 and 1983. It is impossible to know for certain whether there would have been more consistent, sustained and strategic investment in broadband infrastructure if the main telecommunications network infrastructure had remained under state control. However, the evidence presented here does not appear to support the assumption that there would automatically have been consistent and sustained high levels of investment in telecommunications infrastructure if the network had been under state control in the early twenty first century. Based on the patterns of investment exhibited in the twentieth century it is nevertheless reasonable to conclude the state would have invested strongly in broadband infrastructure in the early twenty first century. However, rather than being a function of any strategic prioritising of telecommunications infrastructure, this investment would have simply been a function of the very strong economic growth, cheap credit, and large fiscal surpluses available to the Irish government at that time.

5.6 Appendix to Chapter 5: Supplementary Figures and Tables

Figure 5.A: Depreciation profile of transportable assets – remaining value %

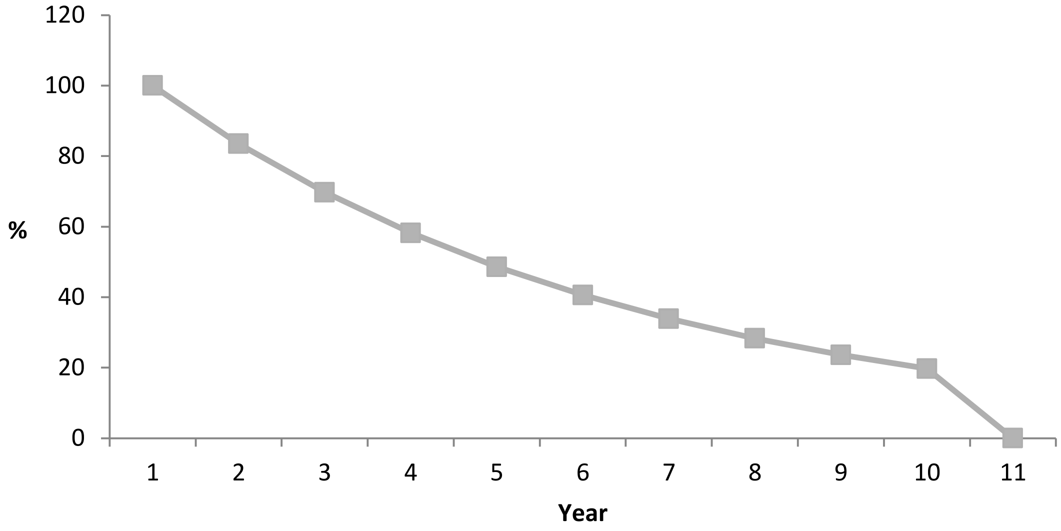


Figure 5.B: Depreciation profile of non-transportable assets – remaining value %

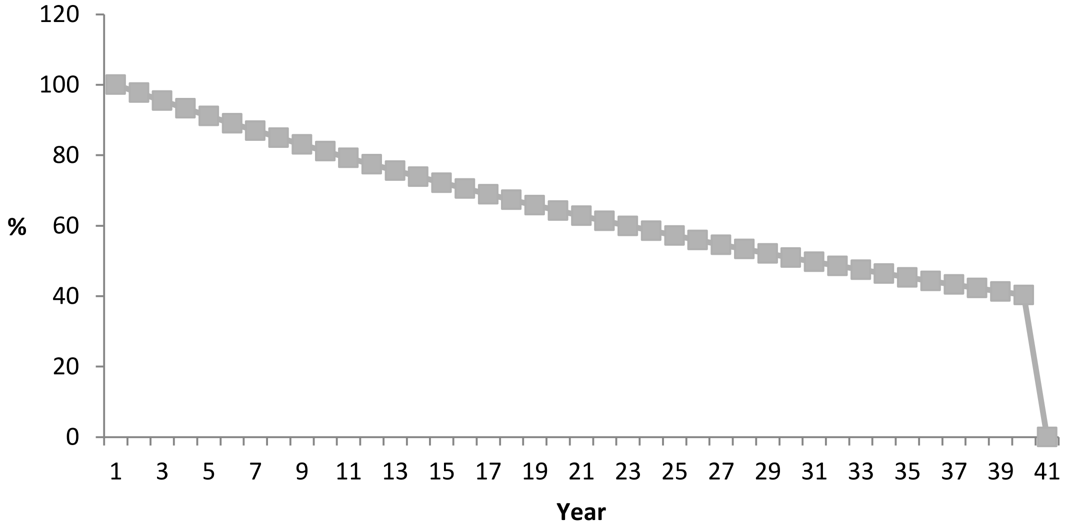


Table 5.A: British Post Office telephone capital holdings in the Irish Free State as of April, 1922 (£)

Value of Plant Sites and Buildings	Change in value of stores held for construction purposes	Total
765,358	13,500	**778,858**

Source: See Table 5.1; Department of Posts and Telegraphs (1923)

Table 5.B: Annual net additions to fixed telephone capital assets in Ireland, 1922 to 1959 (£)

Year	**Value**	**Store**	**Total**
19**22**/23	40,457	13,500	**53,957**
19**23**/24	23,870	1,500	**25,370**
19**24**/25	110,377	16,000	**126,377**
19**25**/26	205,733	0	**205,733**
19**26**/27	130,930	23,000	**153,930**
19**27**/28	127,631	0	**127,631**
19**28**/29	97,617	-20,000	**77,617**
19**29**/30	96,712	0	**96,712**
19**30**/31	73,539	10,000	**83,539**
19**31**/32	54,063	-5,000	**49,063**
19**32**/33	36,690	-5,000	**31,690**
19**33**/34	35,711	-5,000	**30,711**
19**34**/35	51,060	-1,000	**50,060**
19**35**/36	84,479	0	**84,479**
19**36**/37	117,438	0	**117,438**
19**37**/38	241,462	20,000	**261,462**
19**38**/39	253,359	7,000	**260,359**
19**39**/40	151,417	0	**151,417**
19**40**/41	191,225	0	**191,225**
19**41**/42	115,627	0	**115,627**
19**42**/43	70,134	0	**70,134**
19**43**/44	80,234	0	**80,234**
19**44**/45	54,199	0	**54,199**
19**45**/46	88,796	5,000	**93,796**
19**46**/47	371,019	10,000	**381,019**
19**47**/48	365,550	74,000	**439,550**
19**48**/49	837,407	250,000	**1,087,407**
19**49**/50	1,297,336	60,000	**1,357,336**
19**50**/51	1,834,184	0	**1,834,184**
19**51**/52	1,724, 015	660,000	**2,384,015**
19**52**/53	1,364,240	550,000	**1,914,240**
19**53**/54	1,078,257	0	**1,078,257**
19**54**/55	1,587,786	0	**1,587,786**
19**55**/56	2,004,700	-350,000	**1,654,700**
19**56**/57	1,807,084	-180,000	**1,627,084**
19**57**/58	1,301,996	-95,000	**1,206,996**
19**58**/59	1,552,887	-135,000	**1,417,887**

Note: Value represents the value of plant sites and buildings while store represents the change in value of stores held for construction purposes.

Sources: See Table 5.1; Department of Posts and Telegraphs Annual Reports (1923 to 1960)

Table 5.C: Annual net additions, fixed telephone capital assets in Ireland, 1959 to 1980 (IR£)

Year	Telephone plant	Land and buildings	Total
19**59**/60	1,568,455	134,885	**1,703,340**
19**60**/61	2,162,677	109,177	**2,271,854**
19**61**/62	2,290,351	101,686	**2,392,037**
19**62**/63	3,256,255	257,811	**3,514,066**
19**63**/64	4,004,004	360,910	**4,364,914**
19**64**/65	5,519,224	521,821	**6,041,045**
19**65**/66	5,541,991	839,904	**6,381,895**
19**66**/67	5,372,100	460,781	**5,832,881**
19**67**/68	5,884,533	503,756	**6,388,289**
19**68**/69	6,299,101	413,641	**6,712,742**
19**69**/70	7,384,971	533,856	**7,918,827**
19**70**/71	9,018,800	563,428	**9,582,228**
19**71**/72	10,361,406	857,435	**11,218,841**
19**72**/73	16,273,376	1,339,935	**17,613,311**
19**73**/74	21,846,174	1,342,453	**32,188,627**
19**74**	22,080,005	1,588,176	**23,668,181**
19**75**	39,827,116	2,754,059	**42,581,175**
19**76**	41,778,418	3,126,537	**44,904,955**
19**77**	43,178,843	5,044,227	**48,223,070**
19**78**	53,164,926	7,177,419	**60,342,345**
19**79**	60,764,217	11,680,909	**72,445,126**
19**80**	96,680,540	29,973,671	**126,654,211**

Source: See Table 5.1; Department of Posts and Telegraphs Annual Reports (1961 to 1981)

Table 5.D: An Bord Telecom, annual net additions, fixed telephone capital assets, 1981 to 1983 (IR£)

Year	Telephone plant	Land and buildings	Total
1981	201,740,000	18,260,000	**220,000,000**
1982	218,246,000	19,754,000	**238,000,000**
1983	223,748,000	20,252,000	**244,000,000**

Source: See Table 5.1; Government Estimates for Public Service (1981 to 1983)

Table 5.E: Telecom Éireann, annual net additions, fixed telephone capital assets, 1984 to 1998 (IR£)

Year	**Plant and equipment**	**Land and buildings**	**Total**
19**84**/85	207,797,000	12,131,000	**219,928,000**
19**85**/86	126,184,000	3,037,000	**129,221,000**
19**86**/87	137,184,000	1,222,000	**138,406,000**
19**87**/88	121,291,000	1,003,000	**122,294,000**
19**88**/89	108,301,000	4,941,000	**113,242,000**
19**89**/90	143,847,000	7,076,000	**150,923,000**
19**90**/91	151,963,000	22,809,000	**174,772,000**
19**91**/92	142,059,000	8,334,000	**150,393,000**
19**92**/93	156,886,000	2,555,000	**159,441,000**
19**93**/94	160,742,000	2,929,000	**163,671,000**
19**94**/95	167,855,000	4,145,000	**172,000,000**
19**95**/96	196,043,000	1,910,000	**197,953,000**
19**96**/97	261,618,000	6,812,000	**268,430,000**
19**97**/98	290,542,000	5,987,000	**296,529,000**

Source: See Table 5.1; Telecom Éireann Annual Reports (1985 to 1998)

Table 5.F: Cost of living index, 1922 to 1945

Year	**Price Index**
1922	185
1923	180
1924	183
1925	188
1926	182
1927	171
1928	173
1929	174
1930	168
1931	157
1932	153
1933	149
1934	152
1935	156
1936	159
1937	170
1938	173
1939	173
1940	206
1941	228
1942	250
1943	284
1944	296
1945	293

Note: Base year 1914 = 100

Sources: See Table 5.2; Derived from Department of Industry and Commerce, Statistical Abstracts of Ireland (1931 to 1946)

Table 5.G: Index numbers of wholesale prices for capital equipment, 1942 to 1953

Year	Price Index
1942	140.4
1943	148.9
1944	154.9
1945	156.1
1946	165.6
1947	184.2
1948	199.8
1949	200.9
1950	208.3
1951	223.3
1952	248.2
1953	250.4

Note: Base year 1938 = 100

Sources: See Table 5.2; Dept. of Industry and Commerce and CSO Statistical Abstracts of Ireland (1946-54)

Table 5.H: Index numbers of wholesale prices for capital goods, 1954 to 1975

Year	Transportable goods	Building & Construction	Total
1954	99.6	97.9	**98.8**
1955	104.3	100.3	**102.0**
1956	108.8	106.7	**107.8**
1957	112.5	111.5	**112.6**
1958	112.9	113.5	**114.1**
1959	113.3	111.3	**112.9**
1960	114.1	114.5	**115.3**
1961	116.5	119.1	**119.3**
1962	118.2	125.4	**124.1**
1963	119.3	126.5	**125.1**
1964	123.3	136.2	**132.7**
1965	125.2	140.3	**136.3**
1966	128.0	146.6	**141.6**
1967	130.3	152.1	**146.2**
1968	134.8	158.5	**152.0**
1969	142.1	175.6	**165.6**
1970	149.2	195.3	**181.7**
1971	159.2	215.8	**198.8**
1972	168.6	238.2	**217.6**
1973	180.1	270.3	**243.8**
1974	209.6	357.3	**313.1**
1975	249.0	427.9	**374.9**

Note: Base series 1953 = 100

Sources: See Table 5.2; CSO Statistical Abstracts of Ireland (1955 to 1976 inclusive)

Table 5.I: Capital goods price indices (excluding VAT), 1976 to 1985

Year	Capital Goods	Building & Construction
1976	118.5	116.6
1977	139.9	136.7
1978	154.8	150.5
1979	176.8	174.1
1980	206.5	209.5
1981	234.0	239.0
1982	256.8	263.7
1983	273.3	279.1
1984	291.9	298.5
1985	306.1	313.3

Note: Base series 1975 = 100

Source: See Table 5.2; CSO Statistical Abstracts of Ireland (1978 to 1986)

Table 5.J: Capital goods price indices (excluding VAT), 1986 to 1993

Year	Capital Goods	Building & Construction
1986	103.1	102.4
1987	106.3	105.1
1988	110.5	108.7
1989	116.1	117.1
1990	120.1	122.1
1991	123.2	125.4
1992	125.5	127.9
1993	129.1	131.3

Note: Base series 1985 = 100

Source: Table 5.2; CSO Statistical Abstracts of Ireland (1987 to 1994 inclusive); Author's calculations

Table 5.K: Capital goods price indices (excluding VAT): 1994 to 2000

Year	Transportable goods	Building & Construction	Total
1994	131.3	134.3	**132.0**
1995	134.4	139.0	**135.9**
1996	136.2	140.7	**137.8**
1997	137.9	145.6	**140.9**
1998	141.4	149.6	**144.4**
1999	142.7	155.9	**148.2**
2000	145.4	167.6	**155.1**

Note: Base series 1985 = 100

Source: See Table 5.2; CSO Statistical Abstracts of Ireland (1994 to 2000 inclusive); Author's calculations

Table 5.L: Composition of transportable assets at Independence – remaining value by vintage (£)

Vintage	Remaining Value of Stock
1921	2,896,716
1920	2,418,758
1919	2,019,590
1918	1,686,468
1917	1,408,094
1916	1,175,777
1915	981,697
1914	819,771
1913	684,494
1912	571,522
1911	0
Total	**14,662,887**

Source: Author's calculations

Table 5.M: Composition of non-transportable assets at Independence – remaining value by vintage (£)

Vintage	Remaining Value of Stock
1921	427,375
1920	417,631
1919	408,015
1918	398,613
1917	389,424
1916	380,449
1915	371,688
1914	363,141
1913	354,807
1912	346,644
1911	338,652
1910	330,874
1909	323,266
1908	315,830
1907	308,565
1906	301,470
1905	294,547
1904	287,752
1903	281,127
1902	274,674
1901	268,349
1900	262,195
1899	256,169
1898	250,271
1897	244,501
1896	238,860
1895	233,347
1894	227,962
1893	222,705
1892	217,577
1891	212,576
1890	207,704
1889	202,918
1888	198,259
1887	193,686
1886	189,242
1885	184,882
1884	180,651
1883	176,506
1882	172,446
1881	0
Total	**11,257,271**

Source: Author’s Calculations

Chapter Six: Modelling Broadband Adoption, Household Evidence from Ireland

6.1 Introduction

In previous chapters we discussed broadband's importance for long-run growth and Ireland's performance in terms of broadband penetration. Income, education, demographics, the quality and diffusion of pre broadband telecommunications infrastructure and the timing of the start of the diffusion process were all identified as influences on broadband penetration. The focus in chapter four was on differences in country level broadband adoption while in chapter five we examined the historical development of telecommunications infrastructure in Ireland. In this chapter the focus shifts to the individual level and in particular to the broadband adoption decisions of Irish householders. It is possible that Ireland's trailing of the OECD is a function of the characteristics and preferences of Irish consumers. In this context I present a technology adoption framework to help explain Ireland's trailing of the OECD. Possible reasons include: (a) relative lack of broadband awareness, (b) relative lack of broadband availability, (c) relative lack of capacity (financial and otherwise) on the part of Irish consumers to purchase broadband and (d) relative lack of revealed preference for broadband services. Of course Ireland's relatively poor performance might be caused by a combination of all four reasons. The proposed framework builds on the insights of the epidemic and discrete choice models of technology diffusion (see for example Geroski, 2000 and Stoneman, 2001) and also draws upon hedonic demand theory (Lancaster, 1966).

The model underlying the basic empirical strategy is a qualitative discrete choice model of dichotomous decision making. The choices are adoption or non-adoption. Where both choices are available, broadband adoption will occur if the expected net benefit of adoption exceeds the expected net benefit of non-adoption. The logit model is used. The reason for using the logit model is that this particular type of discrete choice model yields a measure called the odds ratio. The odds ratio is a measure of effect size and describes the strength of association between two binary data values. The odds or likelihood of adoption; is assumed to be influenced by the characteristics of both the respondent and the technology, and by the broader market environment. The dataset used in the study is a large 21,201 sample. The sample is a random subset of Ireland's 2006 Census of Anonymised Records, known as the COPSAR dataset. I subdivide the information generated by the COPSAR responses into eight different response categories. The response categories represent current geographic location, personal commitments, education, job status, socio-economic status, personal characteristics, accommodation status and possessions. The different effects exerted by the COPSAR response variables on the odds of a respondent adopting broadband Internet are then estimated using the logit model.

The estimates show that the higher population density locations of Dublin and other urban areas are associated with improved odds of residential broadband adoption. On the other hand, the respondents' geographic location only very weakly influences the odds of adopting Internet access of any type. One implication of the results is that when Internet services are available to purchase, rural and non-Dublin respondents do not display a particular lack of awareness, or revealed preference, for Internet services. In 2006 broadband Internet access principally offered a higher quality but similar functionality to narrowband Internet access. It therefore seems unlikely that rural respondents would have a particular lack of preference for broadband Internet compared to narrowband Internet. This suggests that the effects of Dublin residency and urban residency on the odds of broadband adoption are not best explained by a relative lack of preference or awareness of rural respondents for Internet services. Instead, the results imply that it was the differences in the availability of, and opportunity to acquire, broadband Internet services that was driving urban and rural differences in residential broadband adoption in Ireland.

Perhaps surprisingly the respondents' job status is not found to influence the odds of broadband adoption. Also contrary to expectations is the finding that adding the respondent's level of education to the logit model fails to improve the model's predictive power. The results do however show that variables signifying the respondent's underlying level of wealth and income are positively associated with increased odds of broadband adoption. Specifically, I find that the professional and managerial socio-economic groups have improved odds of broadband adoption while respondents resident in owner occupied accommodation also have improved odds of broadband adoption. Overall the findings suggest that income and wealth, and financial capacity in general, are relevant to the broadband adoption decision. While the geographic location variables have a much stronger effect on broadband Internet adoption than they do on general Internet adoption, the wealth signifying variables have a stronger effect on general Internet adoption than they do on broadband Internet adoption.

What are the implications of these results? Ireland’s high GDP per capita relative to the OECD means that a lack of financial capacity on the part of consumers is not a persuasive explanation for Ireland trailing the OECD. While capacity helps explains broadband adoption decisions it does not explain Irish underperformance. The overall results suggest that policies to increase broadband penetration in Ireland should focus on reducing or eliminating barriers to broadband availability, particularly in non-urban areas, rather than focusing on policies designed to stimulate broadband demand through awareness campaigns or through the subsidy of residential purchases of broadband services.

6.2 Broadband Adoption, Ideas and Evidence

The context of broadband adoption in Ireland

The post-2008 crisis in mainstream economics illustrates the danger of drawing definitive conclusions from single empirical studies or indeed from single methodologies. No single methodological approach in the social sciences can safely be deemed sufficiently robust to draw definitive conclusions about socio-economic phenomena. To complement the country-level study in chapter four I conduct an individual-level case study of Irish broadband adoption patterns. The chapter four results indicated that broadband adoption was positively influenced by higher income and education levels, by higher population density and concentration levels, and by higher levels of diffusion of pre broadband telecommunication goods. By corroborating the chapter four results we can obtain a higher degree of confidence in the results of both studies. As discussed in the earlier chapters, broadband Internet subscription rates are low in Ireland compared to the OECD. Ireland had the third lowest fixed (wired) broadband subscription rate in Western Europe in June 2010, with only Portugal and Greece having lower rates (see Table 6.1). Ireland also ranks third last in DSL broadband subscriptions. The chapter four results suggested that Ireland’s delayed broadband take-off negatively influenced the subsequent rates of broadband penetration. However, other late starting countries such as the United Kingdom were able to subsequently achieve penetration rates in excess of the OECD average (Forfás, 2010). I argued in chapter four that Ireland’s low population density may have inhibited broadband penetration. However, low population density is not a sufficient explanation for Ireland’s trailing of the OECD. The Scandinavian countries of Iceland, Norway and Sweden all have very low population density yet have nonetheless succeeded in achieving amongst the highest broadband penetration rates in the world. A lack of strong early competition from cable technology may also have inhibited broadband diffusion in Ireland; however competition from cable also failed to develop in many other European countries, and

Iceland, France and Germany have all achieved above average penetration rates without achieving extensive cable broadband penetration.

Table 6.1: Fixed (wired) broadband subscriptions in Western Europe as of June 2010

Rank	Country	Total	DSL Platform	Other Platforms
1	Netherlands	37.8	22.0	15.7
2	Denmark	37.3	22.3	15.1
3	Switzerland	37.1	25.9	11.2
4	Norway	34.2	20.2	14.1
5	Luxembourg	34.1	28.0	6.1
6	Iceland	33.3	30.5	2.8
7	Sweden	31.8	17.5	14.3
8	France	31.4	29.7	1.7
9	Germany	31.3	27.9	3.5
10	United Kingdom	30.5	24.1	6.4
11	Belgium	30.0	16.7	13.3
12	Finland	26.4	21.8	4.6
13	Austria	23.0	15.9	7.1
14	Spain	22.2	18.0	4.2
15	Italy	21.3	20.9	0.5
16	**Ireland**	**20.3**	**16.3**	**4.0**
17	Portugal	18.9	10.5	8.3
18	Greece	18.7	18.7	0.0

Note: Totals represent the number of fixed (wired) broadband subscriptions per 100 inhabitants. EU15 plus Iceland, Norway and Switzerland

Source: OECD (June 2011, Table 1D (1))

As discussed in chapter five the slow diffusion of broadband has followed the historical trend of generally slow telecommunications diffusion in Ireland. This trend has long been dismissed as a demand problem by official sources. Eamonn Hall (1993, p.38) describes how the Chancellor of the Exchequer Sir Michael Beach justified lack of investment for telephone services in the early twentieth century on the grounds that long-distance communication was not of interest to ordinary people. In the 1940s, the Department of Posts and Telegraphs was forced to defend itself against the arguments of the Cabinet Committee on Economic Planning that the Department was underperforming. According to Hall (1993, p.54-55), the Department based its argument on the claim that, even under the most favourable economic conditions, a figure of 130,000 telephone instruments would represent saturation in Ireland, and that there simply wasn't widespread demand for the telephone. The Government subsequently sided with the Department. In 2006, the then Minister for Communications was reported (Mulley, 2006) to have identified lack of demand as a key reason for the low rate of broadband penetration in Ireland, while the Department of Communications even went so far as to launch a public consultation into this perceived lack of demand. So does Ireland have a relative lack of demand for broadband and other telecommunication services compared to the OECD? If so, what is driving this lack of demand, and what are the implications for broadband policy? These questions motivate the current study.

The diffusion of technology: Empirical evidence

There is a large body of empirical evidence which helps explain variations in technology adoption. Rates of technological change and technology adoption vary greatly across countries, regions, industries, firms, households and individuals. The diffusion of information technologies and their associated activities have been found to be spatially uneven within different regions of countries. At a geographic level, Tony Grubesic (2002) identifies differences in Internet activity between urban and rural locations in Ohio. The seminal work of Richard Nelson and Edmund Phelps (1966), and of Nathan Rosenberg (1972), finds that differences in human capital help explain variation in adoption rates between firms. The availability of finance also has implications for a firm's ability to invest in new technology. Edwin Mansfield (1964) and Eleonora Bartoloni and Maurizio Baussola (2001) find that firm size, which affects the availability of finance, positively influences a firm's propensity to adopt new technology. Paul David (1975) finds that because most costs of adoption are fixed, the choice of adoption is influenced by the scale of the firm as well as by the market size and structure of the industry in which the firms operate. Francesco Caselli and Wilbur Coleman (2001) and Hyunbae Chun (2003) identify the importance of human capital and educational attainment for technology adoption at the firm level. In the Irish context, Stefanie Haller and Iulia Siedschlag (2007) identify unevenness in the adoption of ICTs across firms, industries and space, while Dimitrios Pontikakis and Patrick Collins (2010) find that firm level broadband adoption is uneven across industrial sectors. Haller and Siedschlag's results suggest that successfully adopting Irish firms tend to be larger, younger, fast growing, skills and export intensive, and located in Dublin.

Eric Brynjolfsson and Lorin Hitt (2003) find that the impact of ICT on productivity and growth is greater at firm level than it is at country level. The needs of the business sector are the principal broadband focus of the Irish government's development agencies (Enterprise Ireland, IDA and Forfás). This particular focus is reflected, for example, in *Ireland's Advanced Broadband Performance and Policy Priorities* (Forfás, 2011). The report emphasises the importance of meeting the current and future advanced broadband needs of the enterprise base. Forfás argue that the widespread availability of advanced broadband infrastructure and services for the business sector, will capture opportunities for productivity and innovation, and that access to advanced broadband services will be important for realising future growth potential (Forfás, 2011, p.10). Nonetheless, by the end of 2010, Ireland's enterprise take-up rate for broadband of 87 per cent was similar to that of the EU15's enterprise take-up rate of 89 per cent (Forfás, 2011, p.47). Ireland's 'lagging' in terms of broadband diffusion is far more pronounced for household take-up than it is for enterprise take-up. Just 58 per cent of households in Ireland subscribed to broadband at the end of 2010 compared to over 80 per cent in the leading EU15 countries such as Sweden. What might explain Ireland's lagging of the EU15 for household take-up of broadband?

My focus in this chapter is on the causes underlying the variation in residential broadband adoption in Ireland. How can we explain differences in residential broadband adoption? Differences in broadband adoption between types of household have been identified in the empirical literature. For example, Grubesic (2002) finds that Internet activity is higher in geographic locations with higher income levels, with educational institutes, and with higher population density. Susan O'Donnell, Helen McQuillan and Anna Malina (2003) find using Irish data that those most likely to be late Internet adopters include the retired, those over fifty five, those with little education, small farmers and those working in agriculture, forestry and fishing. Rappoport, Kridel, Taylor and Alleman (2003) find income and education to be strong predictors of purchases of broadband services at the individual level, while Kenneth Flamm and Anindya Chaudhuri (2007) find that rural/urban differences impact on broadband adoption, with urban residents being more likely to adopt. Flamm and Chaudhuri (2007) also find that household adoption patterns for broadband access are uneven and affected by socio-economic factors. Based on interviews with stakeholders in Scotland, Susan Howick and Jason Whalley (2008) identify relative cost and preference for technologies whose use is enhanced by broadband as influences on the decision of householders to adopt broadband. The presence of children in the household was also seen as positively influencing the adoption decision because children raised the ICT competence of the household.

There are a number of models of technology diffusion, see for example Paul Geroski, (2000) and Massoud Karshenas and Paul Stoneman, (1995) for overviews of these models. The empirical strategy used in the current study is based on the discrete choice model of technology diffusion. The discrete choice model was described in chapter two. A key assumption of discrete choice models is that certain differences between individuals will partially explain technology adoption decisions. A common goal of the discrete choice models is to identify which characteristics of individuals explain technology adoption differences, as well as the degree to which those characteristics influence the adoption differences. So what are these characteristics likely to be?

Understanding consumer technology adoption

Kelvin Lancaster (1966) argues that consumers making purchases are not seeking to acquire goods and services themselves. Rather, consumers are seeking to acquire the characteristics contained within those goods and services. According to Lancaster, what customers actually want is not so much a specific product, but the particular bundle of characteristics and the ‘utility’ provided by those characteristics. In the case of broadband, characteristics sought by consumers may include long-distance communication or fast access to information. The assumption is consumers with perfect information can acquire any combination of characteristics they desire, subject only to budget and opportunity constraints. Lancaster’s hedonic demand theory is a revealed preference method of estimating the demand for, or value assigned to, a particular good or service. The hedonic demand theory decomposes the good or service into its constituent characteristics (such as life span and quality), and then obtains estimates of the contributing value of each characteristic. However, the expected benefits of different goods and services should not be considered in isolation from their respective costs. For example, if there is a relative increase in the cost of access to broadband substitutes, then all things being equal we would expect the demand for broadband access to increase. Everett Rogers (1983) argues that each potential technology adopter holds a unique perception of the technology’s relative advantage. The perceived relative advantage is the total positive utility from the technology’s characteristics that a potential adopter expects to enjoy, less the total expected costs involved including opportunity costs. A higher expected net benefit from adoption, i.e. the perceived relative advantage, is expected to be associated with a higher probability of adoption (Hall, 2005). One useful characteristic of broadband access is the ability to facilitate long-distance communication. The costs of broadband enabled methods of communication, for example, email, Skype, and Internet forums are generally independent of physical distance. On the other hand, the costs of certain other methods of long-distance communication are very much dependent on physical distance. For example, it is more expensive to make telephone calls internationally than it is locally. Longer distances are also associated with increased travel time for face-to-face communication and with higher transportation costs. Thus the relative advantage of using broadband as a means of communication is likely to increase as the physical distance between the communicators' increases. The implication is that consumers with relatively strong needs or preferences for long-distance communication will assign a greater relative advantage to broadband access, and should therefore display a greater revealed preference for broadband.

Consumers differ in their characteristics. Technology adoption decisions are variously facilitated and/or inhibited by different factors, and these factors will include the characteristics of the individual consumers. Technology adoption requires a number of conditions to be fulfilled. In Table 6.2 I present a framework for explaining technology adoption that draws on basic economic principles such as those described in the epidemic and discrete choice models of technology diffusion. The framework presented in Table 6.2 considers the issue of adoption from the perspective of the potential technology adopter (i.e., the consumer). I divide reasons for non-adoption into four categories. The four categories are: (a) Issues related to *awareness* of the technology. As the epidemic models presume, the consumer must become aware of the existence of the technology. Consumers clearly won't adopt a technology if they aren't aware of it. (b) The second category relates to *opportunity* and this includes issues of availability. It must be possible for the consumer to have the option of purchasing or otherwise obtaining the technology. Again, consumers clearly can't adopt a technology if the choice to adopt is not available to them. (c) The third category is related to the consumer's *capacity* to obtain the technology which may include financial issues. The consumer's capacity in terms of resources, financial and otherwise, will influence the consumer's decision to adopt or purchase the technology and may even completely preclude the possibility of adoption. (d) Finally, as the discrete choice models presume, the consumer's perception of the *utility,* or relative advantage, of the technology will influence the adoption decision. This may include issues related to the consumer's preferences, experience or competence.

Table 6.2: Questions underpinning the technology adoption decision

Category	Question	Relevance
A	Is the consumer ‘**aware**’ of the technology?	Education, Experience, Physical location, Contact with existing users
B	Does the consumer have the ‘**opportunity**’ to acquire the technology?	Technological constraints, Infrastructure constraints, Market constraints, Legal constraints, Physical location
C	Does the consumer have the ‘**capacity**’ to acquire the technology?	Income and wealth, Access to finance, Education and skill-set, Social contacts
D	What is the consumer’s anticipated level of ‘**utility**’ from the technology?	Personal preferences, Perceived relative advantage, May be a job requirement, Familiarity with similar technology

I anticipate that broadband adoption requires an affirmative response to the first three tests described in Table 6.2. In other words, awareness, opportunity and capacity are assumed to be necessary but insufficient conditions for conscious adoption. It is further anticipated that the greater the consumer’s expected utility from broadband adoption, the greater will be the consumer’s probability of adoption. The population’s underlying preference for broadband will influence the overall level of demand. Although Ireland’s fixed broadband penetration rate trails the OECD, the adoption rate for other technology goods, including mobile phones and cable televisions, is above average compared to the OECD (OECD, 2007). Given that Irish consumers are so willing to adopt other ICT technologies; it is difficult to see why Irish consumers would have a particular lack of preference for, or indeed awareness of, broadband compared to other OECD consumers. In the empirical section I consider whether a relative lack of preference can explain adoption patterns in Ireland. On the other hand it may be that certain constraints are diminishing opportunities for Irish consumers to adopt broadband. In this context I also consider opportunity related explanations for broadband adoption.

6.3 Strategy for Modelling Household Level Broadband Adoption: The Logit Model

Basic discrete choice models

How can we formulate, test and then estimate a model of the broadband adoption decision? In the current section I draw on Daniel McFadden (1974, 1981, and 1984); Takeshi Ameniya (1990); Jan Cramer (1991) and Rosa Matzkin (2007). As it is not possible to partially subscribe the broadband adoption decision is a dichotomous Yes/No decision. There is either an existing subscription or there is not. According to Robert Fairlie (2005), qualitative discrete choice models are naturally suited for the examination of dichotomous decision making. I make a number of assumptions. First, each responding householder in the dataset is assumed to have a subjective and unique perception of the ‘expected net benefit’ from adoption of the technology. Second, each respondent is assumed to have a unique minimum threshold value for their expected net benefit – if the benefit exceeds this amount the respondent is predicted to subscribe to the technology. On the other hand, if the respondent’s expectation of the net benefit does not exceed the respondent’s unique minimum threshold point, the respondent is predicted not to adopt the technology. As Matzkin (2007) explains, in a discrete choice model the individual must choose one alternative out of a finite set of two or more mutually exclusive alternatives. In the current study the individual respondent must choose either to:

(a) Subscribe, or

(b) Currently refrain from subscribing

Each choice available to the individual respondent is characterized by a vector of *n* positive and negative attributes. For example, ease of communication is a positive attribute of broadband adoption while the monetary cost of subscription is a negative attribute of adoption. Following Aneniya (1990), I assume that the respondent will choose the discrete alternative he or she perceives will maximize his or her expected utility over the set of available alternatives. Thus, provided that both choices are available, adoption will occur if the expected net utility of adoption exceeds the expected net utility of non-adoption. The respondent's expected utility from each alternative will contain both observable and unobservable components (Cramer, 1991).

According to Jan Cramer (2003), the three most common discrete choice models in the economics literature are the linear probability model; the probit model and the logit model. However, the linear probability model is unsuitable for estimating dichotomous decisions because the disturbance terms in linear probability models are heteroskedastic, and also because the conditional expectation for the dependent variable in the linear probability model is not bounded between zero and one. In the current study I estimate the different effects of a set of predictor variables on the adoption decision using a logit model rather than the closely related probit model. The main reason is that in situations of discrete choice the logit model permits a specific interpretation of the estimates in terms of the respondent's perceived utility maximisation. In particular, the logit model has a logarithmic structure which yields a measure called the 'odds ratio' (Cramer, 1991). The odds ratio is a measure of effect size and describes the strength of association between two binary data values. Odds ratio measurements reveal the marginal effect of a unit increase in the independent predictor variable, for example an additional year of education, on the likelihood of the dependent variable being 'true' – which in the current study is the likelihood of the respondent choosing to subscribe to the technology. A higher odds ratio means an improved probability of adoption.

In the logit model the probability of a particular option being chosen is estimated as a function of a set of independent predictor variables. To illustrate, suppose option Y_j represents a discrete choice among *k* alternatives. Each alternative choice is treated as having a random component because the choice depends on random utilities. The choice has a random utility because different respondents have different preferences, expectations and needs. Let U_{ij} represent the expected utility of the j-th choice to the respondent *i*. The expected utility of the choice has a systematic component V_{ij} which reflects the characteristics of the choice such as its entertainment value and its net cost, while the utility of the choice also has a random component e_{ij}. The expected utility of the choice *j* for respondent *i* can therefore be expressed as:

$$U_{ij} = V_{ij} + e_{ij} \tag{6.1}$$

I assume that the respondents act in a rational way and attempt to maximize their utility. Where there are *k* available options to choose from, respondent *i* will choose alternative *j* only if he or she expects that alternative U_{ij} will provide the greatest utility of every available option ranging from U_{i1} to U_{ik}. The probability of respondent *i* choosing option *j*, is equal to the probability that U_{ij} provides the greatest utility of all available alternatives. This is shown as:

$$P_{ij} = \Pr(Y_i = {}_j) = \Pr(\max(U_{i1} \ldots\ldots U_{ik}) = U_{ij}) \tag{6.2}$$

A number of authors (see for example Gangadharrao Maddala, 1983) have shown that if the error terms e_{ij} have standard Type I extreme value distributions, as opposed to normal value distributions, then:

$$P_{ij} = \exp(V_{ij})/\exp(V_{ik}) \tag{6.3}$$

Where *k* represents every option available to choose other than option *j*

The technique most frequently used to estimate logit models is known as the maximum likelihood method; see for example Forrest Nelson, (1990) and Cramer, (1991). Maximum likelihood estimates for the parameter vector have nonlinear first order conditions. This means that iterative methods must be employed to find explicit solutions. The model used for the purposes of this study is a dichotomous model. The dichotomous model is the simplest type of discrete choice model and is the special case where there is just a binary choice set. In other words the value of *k* in Equation 6.3 is equal to two. The interpretation of the dichotomous model is straightforward. The respondent *i* will choose the first alternative if U_{i1}-$U_{i2} > 0$ and will choose the second alternative if U_{i2}-$U_{i1} > 0$. If the respondent's random utilities exhibit independent extreme value distributions then their differences will have a logistic distribution. Using the standard logistic regression model this permits an economic interpretation of the adoption decision in terms of utility maximisation.

The COPSAR dataset

In order to credibly defend any empirical methodology and results we must control for the main sources of potential selection bias. If there is substantial selection bias then the empirical results are invalidated. The problem of selection bias can be solved by randomly assigning individuals to one of either a treatment group or control group (Wooldridge, 2002, p.129). To determine whether the results are meaningful we must compare the pre-treatment characteristics (for example education and age) of the different groups to ensure they are sufficiently similar. The randomisation is considered successful provided the pre-treatment differences between the treatment and control groups are sufficiently small enough. Individuals in the treatment group are then exposed to the effect we want to test while individuals in the control group are not exposed to the effect. Provided the selection bias is sufficiently small, the difference in the post-treatment outcomes across the treatment and control groups can be deemed to capture the average effect on the dependent variable that is being caused by the manipulated variable (Angrist and Pischke, 2009).

The dataset used in the present study is a subset of the COPSAR dataset. The COPSAR dataset is Ireland’s 2006 Census of Population Sample of Anonymised Records (CSO, 2006). COPSAR is a large random sample of the population and therefore selection bias should be minimal. The Census was conducted on the night of 23 April 2006. The Census recorded answers relating to the size and composition of the population within the boundaries of the state. Residents temporarily absent from the location are excluded from the count. The Census enumerators recorded answers to questions concerning visitors present on 23 April, as well as questions concerning usual residents who were temporarily absent. The Census data is provided by individuals to the Central Statistics Office (CSO) and is qualitative in nature. The CSO anonymised the data for the sample by excluding certain answers capable of identifying households or individuals (such as their name), and by recoding other answers that could lead to the identification of an individual (such as their exact location). Following the anonymisation process there are thirty eight separate questionnaire responses remaining in the COPSAR dataset. A number of the remaining questionnaire responses in the COPSAR dataset are not suitable for quantitative analysis because they are presented as non-numeric string variables and/or because they are presented as categorical variables. For example, the ‘county of residence’ variable is recorded as a non-numeric and categorical variable. I recoded each remaining response into numeric and ordinal variable forms to make them usable for quantitative analysis. All of the newly created variables are ordinal level dummy variables.

The first step is to identify and isolate the questionnaire responses relevant to the adoption decision. Referring back to the categories outlined in Table 6.2, there appears to be a number of variables in the dataset capable of influencing knowledge or ‘awareness’ of new technologies. Respondent characteristics likely to facilitate or inhibit awareness of broadband will also influence the probability of broadband adoption. Examples of such characteristics might include education related variables, job related variables, socio-economic status variables and geographic location variables. The questionnaire responses most likely to influence the ‘opportunity’ to adopt broadband are the geographic location variables. For example, respondents living in rural and low population density areas may be unable to acquire broadband because of difficulties with service provision or other market constraints. Questionnaire responses likely to influence the ‘capacity’ to acquire broadband include the education related variables and, perhaps most importantly, variables associated with income and with wealth. Responses likely to be good proxies of income and wealth include the job related variables as well as the socio-economic status variables. The responses related to the type of accommodation enjoyed, and the responses signalling the ownership of possessions, are also likely to be good indicators of the respondent’s underlying level of income and/or wealth.

Perceived ‘relative advantage’ is arguably the most difficult of the Table 6.2 categories to link to questionnaire responses. It is a challenge to identify questionnaire responses which provide information about the respondent’s perceived relative advantage. Nevertheless, the dataset appears to contain a number of response variables which might plausibly increase the perceived relative advantage of broadband. Respondents with such characteristics are expected to be more likely to adopt broadband. For example, preference for long-distance communication will be a function of the respondent’s physical separation from the people with whom he or she wishes to communicate. Thus physical separation, which I term here as ‘social displacement’, may be associated with, and therefore a suitable proxy for, perceived relative advantage of broadband. A second example is experience with Information Communication Technology (ICT). Respondents’ with experience of ICT are likely to have a greater understanding of, and ability to exploit, the benefits of ICT, and are therefore likely to assign greater value to ICT products and services. Higher education is a promising proxy for ICT experience because training in ICT is a common element of most higher education courses. In addition, many types of job are reliant upon ICT and it is conceivable that workers in such jobs will have greater familiarity with broadband’s advantages and thus assign it a higher relative advantage.

The questionnaire responses of interest are those expected to influence either the respondent’s awareness of the technology, the respondent’s opportunity and capacity to acquire the technology, or the respondent’s perceived relative advantage of the technology.

For ease of analysis I subdivide the remaining COPSAR variables into eight different types. The different types are shown in Table 6.3 where potential sources of influence on broadband adoption decisions are identified.

Table 6.3: COPSAR variable types and possible direct or indirect relevance to broadband adoption

	Variable Type	**Possible Relevance to Broadband Adoption**
a	Current geographic location	Awareness, Opportunity, Utility
b	Personal commitments	Utility
c	Education	Awareness, Capacity, Utility
d	Job status	Awareness, Capacity, Utility
e	Socio-economic status	Awareness, Capacity, Utility
f	Personal characteristics	Awareness, Capacity, Utility
g	Accommodation status	Opportunity, Capacity, Utility
h	Possessions	Capacity

Note: Assumed relevance is purely indicative and not all variables of the same type are expected to have the same or indeed any relevance to broadband adoption

The most important of the questionnaire response variables is the ‘access to the Internet’ questionnaire response. This variable is identified in Table 6.4 under variable type h (possessions) as response H2. The H2 variable identifies whether the respondent has either (a) no Internet access, (b) only dial-up Internet access, or (c) full broadband Internet access. The H2 variable is the outcome variable of interest in the discrete choice model. There are a number of variables in the COPSAR dataset which might plausibly influence the respondent’s adoption decision. Based on the discussion in chapter four, income and wealth related variables, educational attainment related variables and population density related variables will be of particular interest. If such variables are not directly represented in the dataset, as is the case for income, then where possible I use alternative variables as proxies for the variable of interest. The reason income data was not gathered by the census enumerators was to encourage people to fill out the census.

Table 6.4: The COPSAR variables

Variable Type	Response	Respondent Characteristic	Explanation	Possible Responses
(a) Current Location	A1	Regional authority	Regional authority where enumerated	8
	A2	COUNTY	The administrative county where enumerated	34
	A3	Usual residence now	Whether this is the person's usual residence	4
	A4	Residence 1 year ago	Whether this was the residence 1 year ago	6
	A5	Area type	Identifies whether the area is urban or rural	2
	A6	Place of birth flag	Whether county/country of birth is still the usual residence	5
(b) Personal commitments	B1	Marital status	Whether married, single, divorced etc.	5
	B2	Unpaid carer	Whether the person provides unpaid personal help	3
	B3	Voluntary activities	Whether the person does voluntary work	3
	B4	Religion	Identifies type of religion or none	5
(c) Education	C1	Level of education completed	For example primary or secondary	7
	C2	Third level qualifications	Identifies type of 3rd level qualifications if any	13
	C3	Age full time education ceased	Person's age when finishing education	11
(d) Job	D1	Present status	Present principal status e.g., working for payment or profit, or unemployed	9
	D2	Employment status	Type of employment status e.g., employee or self-employed	5
	D3	Industry class	Nature of business carried on e.g., agriculture or manufacturing	10
	D4	Occupation group	Current or previously held occupation e.g., farming or building worker	10
(e) Socio-economic status	E1	Socio-economic group	Current or former occupation of the household's principal earner e.g., professional or unskilled	11
	E2	Social class	Categorises persons by level of occupational skill e.g., skilled or unskilled	7

Source: Census of Population Sample of Anonymised Records (CSO, 2006). The different categories of variable type are the author's own. Table continues on the next page.

Table 6.4 (continued): The COPSAR variables

Variable Type	Response	Respondent Characteristic	Explanation	Possible Responses
(f) Personal characteristics	F1	Sex	Whether the person is male or female	2
	F2	5 year age group	Identifies the person’s 5 year age cohort	16
	F3	Ability to speak Irish	Whether the person can speak Irish	3
	F4	Frequency of speaking Irish	For example daily, weekly or never	8
	F5	Nationality	Whether the person has Irish nationality	3
	F6	Disability	Whether the person has a disability	2
	F7	Ethnicity	Whether the person is ethnically Irish	3
	F8	Place of birth	Identifies place of birth	34
	F9	Year of taking up residency in Ireland	When the person moved to Ireland from abroad	9
	F10	Country of previous residence	Identifies the country of previous residence	7
(g) Accommodation	G1	Type of accommodation	Indicates type of accommodation e.g., bed-sit or semi-detached	8
	G2	Nature of occupancy	For example owner occupied or rented	3
	G3	Year built	Indicates the era the accommodation was built	10
	G4	Central heating	Indicates whether the household has central heating	3
	G5	Type of piped water supply	For example public main or private source	5
	G6	Sewerage facilities	Indicates the type of sewerage facilities	5
(h) Possessions	H1	Number of cars	Indicates number of cars owned or available for use	6
	H2	Access to the Internet	Indicates the type of Internet access if any	4
	H3	Personal computer	Indicates whether the household has a PC	3

Source: Census of Population Sample of Anonymised Records (CSO, 2006). The different categories of variable type are the author’s own.

So which variables in the dataset are of particular interest to broadband adoption? Variables related to education and to income are good candidates. There are three education variables in the COPSAR dataset. These are the category (c) variables shown in Table 6.4. While no information directly related to income was recorded in the questionnaire there are a number of variables in the dataset which are plausible proxies for income. These include the four job status variables in category (d) and the two socio-economic status variables in category (e). Job status and socio-economic status are credible indicators of income and wealth. Respondents from the professional and managerial socio-economic groups (which are groups A, B and C within the CSO's socio-economic group categorisation) are likely, on average, to have higher disposable incomes and levels of underlying wealth than the rest of the population. Having a job is also likely to be strongly associated with higher income levels, while individuals with certain types of jobs are more likely to benefit from Internet access at home and may even be required to do so as a condition of work. It is often prudent to include no more than one variable of each closely related type in the final multivariate model e.g., education, job status, and socio-economic status, in order to minimise the risk of multicollinearity.

The location variables represented in category (a) may impact on the adoption decision through a variety of channels. For example, the respondent's location may impact on the perceived relative advantage of the technology, and may also impact on the respondent's awareness of, and opportunity to acquire, the technology. As described in the earlier chapters, high population density areas such as urban locations are more commercially viable locations for infrastructure providers to service. This is because higher population density reduces per capita costs of infrastructure provision, while local market size also tends to be larger and this generates more revenue for the infrastructure provider. It is expected the greater commercial viability of servicing urban locations will mean Internet availability and quality will be greater in these locations. In extreme cases Internet services may be completely unavailable in rural areas. In addition, if Internet access has been available longer in urban areas then it will have had longer to diffuse, thus providing more time for awareness of the technology to spread through social and business networks. Finally, the more commercially viable high population density areas are likely to have greater competition in the market for Internet service provision. This suggests more competition and a better quality of service in urban locations, and therefore greater net benefits from adoption.

Some of the geographic location variables may also provide information about the respondent’s level of social displacement. Social displacement represents the respondent’s physical separation from friends and families. Individuals with higher levels of social displacement may have greater preference for long-distance communication. Recent migrants, whether to a new county or to a new country may experience higher than average social displacement, thus having increased preference for long-distance communication. The variable in the dataset most closely related to social displacement is the ‘usual residence 1 year ago’ response. This is shown as variable A4 in Table 6.4 and indicates whether the respondent was ordinarily resident in a different county or country twelve months prior to census night. Such individuals are likely to experience relatively high levels of social displacement and, if so, may perceive a greater relative advantage to acquiring broadband.

The accommodation variables (category g) and the possession variables (category h) provide information about the lifestyle and wealth of the respondent. In particular, the G2 variable records whether the respondent is in purchaser/owner-occupied accommodation or in renter occupied accommodation. The property owning group is likelier to be wealthier on average and/or to have higher income on average than the renter group. This is indicated by the very fact that the home owner has property. High mortgage repayments may reduce the capacity of the respondent to purchase non-necessities such as broadband Internet access. On the other hand, owner occupiers are likely to have a greater personal commitment to their accommodation and may therefore have greater preference for ‘upgrades’ such as broadband Internet access. A standard twelve month contract is a significant disincentive to a person in transitory accommodation, in particular if the individual anticipates living somewhere else in six or nine months’ time. The more transitory renter group is likely to be experiencing greater social displacement. If so this would suggest a greater preference for long-distance telecommunications access and renters might perceive greater relative advantage to broadband access. Therefore I consider the expected effect of the home ownership variable on the broadband adoption decision to be ambiguous *a priori*.

A number of the personal characteristic variables in category (f) may plausibly influence broadband adoption. For example, the ethnicity and nationality variables (F7 and F5) are suggestive of social displacement because the respondents from non-Irish groups may be geographically more separated from their social network than the indigenous Irish respondents. The Irish and non-Irish groups might also differ for a number of other reasons. For example there may be different cultural preferences for technology. Finally, the age variable F2 may also influence the adoption decision as respondents of non-working age may be less likely to adopt due to having smaller disposable incomes. Respondents of working age may also assign greater relative advantage to Internet access because of the Internet's utility in aiding job search and in maintaining contact with professional associates and the work place.

Basic empirical model of broadband adoption

The empirical model is a discrete choice logit model which estimates the different effects exerted on the odds of broadband adoption and on the odds of general Internet adoption by the questionnaire response variables contained within the COPSAR dataset. The questionnaire responses are used to develop a set of proxy variables representing, amongst other things, the individual's education levels, income levels, and geographic location. An adoption event is considered to have occurred if the respondent has a residential Internet access connection. I assume the adoption decision is influenced by the characteristics of the respondent, the characteristics of the technology, and the wider socio-economic and market environment. The main purpose of estimating separate models for broadband adoption and general Internet adoption, and then comparing the differences between the two models, is to isolate the influence on the adoption outcome caused by perceived relative advantage (utility) from the influence on the adoption outcome caused by service availability (opportunity).

The respondent's binary choice between adoption and non-adoption is modelled using a random sample of 21,201 qualitative questionnaire responses. The dataset used is a random 10 per cent subset of the full COPSAR random sample. Although discrete choice variables behave like continuous variables when aggregated over many responses, and can therefore be subjected to standard regression analysis, when we wish to model the behaviour or decision of an individual economic unit a discrete choice model becomes necessary (Ameniya, 1990). Jeffrey Wooldridge (2006) and Joshua Angrist and Jorn-Steffen Pischke (2009) describe how econometric techniques can be used to establish causality between socio-economic variables. The causal influence exerted by the predictor variables on the likelihood of adoption is defined as the functional relationship describing what a particular respondent would do given different values for the predictor variables (Angrist and Pischke, 2009). The causal relationship tells us the average decision of a respondent with a particular characteristic. For example, if education is a predictor variable, the functional relationship will describe the changed likelihood of Internet adoption caused by a change in the respondent's education.

The discrete choice logit model estimates the functional relationships underpinning the broadband Internet and the general Internet adoption decisions. The key statistic is the odds ratio which is the ratio of the odds of an event occurring in one group, for example urban residents, to the odds of it occurring in a different group, for example rural residents. An odds ratio exceeding 1 indicates that the event is more likely to occur in the first group. To ensure the estimated causal relationships are unbiased, and for our causal inferences to be valid, it is sometimes necessary to hold various control variables fixed (Wooldridge, 2006). To be confident we are minimising bias and accurately measuring the different effects of the various independent variables on the adoption decision we must first ensure the treatment group and the control group for each of the independent variables is probabilistically equivalent. We can minimise bias if the mechanism of random assignment to groups is used. The COPSAR dataset was chosen by the CSO based on random assignment and we can therefore be confident the characteristics of the treatment and control groups are comparable for each of our independent variables. For this reason I do not add additional control variables to the model.

The basic logit model expressing the odds of technology adoption for respondent *i*, is shown in Equation 6.4. The basic model is:

$$(\text{Adoption Outcome})_i = f(\beta_0 + \beta_n X_i + \varepsilon_i) \qquad (6.4)$$

The generic binary choice variable representing the technology adoption decision is equal to 1 (Yes) if the respondent *i* chooses to adopt the technology and is otherwise equal to 0 (No). X_i represents a vector of independent respondent variables and ε_i is a random error term specific to respondent *i*. The β values are the coefficients to be estimated and represent the marginal effects on the respondent's adoption decisions caused by the predictor variables. The set of predictor variables expected to variously influence the adoption decisions are described in Table 6.5.

Table 6.5 Predictor variables for broadband adoption and for general Internet adoption

Variable name	**Notation**	**Response**	**Binary response – 1 (Treatment group)**	**Binary response - 0 (Control group)**
Internet adoption	Inter	H2	Has Internet access of any type	All other responses
Broadband adoption	Bband	H2	Has Internet access with broadband	All other responses
Dublin	Dub	A2	Located in Dublin City, South Dublin, Fingal, or Dun Laoghaire-Rathdown	All other counties
Urban	Urb	A5	Located in urban area	Located in rural area
Working Age	Age	F2	Respondent is aged 20 to 64	All other age cohorts
Higher Education	Edu	C1	Third Level (non-degree) or third Level (degree or higher)	Has not attended third level or did not state level of education
Job Status	Job	D1	Working for payment or profit	All other statuses For example child, student, retired, unemployed
Higher Socio-economic	ABC	E1	Employers and managers, higher professional, or lower professional	All other socio-economic segments. For example unskilled and farmers
Nature of Occupancy	Home	G2	Resides in purchaser/owner-occupied accommodation	Resides in rented, including rent free, accommodation
Nationality	Nat	F5	Identifies as non-Irish nationality	All other responses including not stated
Ethnicity	Eth	F7	Identifies as non-Irish ethnicity	All other responses including not stated
Recent Migrant 1	Mig1	A4	Resided in different county or country, or no response	Same as now
Recent Migrant 2	Mig2	A4	Resided in different county or country	Same as now or no response
Recent Migrant 3	Mig3	A4	Resided abroad or no response	Resided in Ireland
Recent Migrant 4	Mig4	A4	Resided abroad	Resided in Ireland or no response

Note: Technically speaking the two dependent variables Internet and Broadband (the choice variables) do not divide into treatment and control groups. They are nonetheless included here for completeness. Responses in the treatment group are coded ‘1’ in all cases, while responses in the control group are coded ‘0’ in all cases.

Using the notation shown in Table 6.5, the preliminary empirical models for the generic Internet adoption decision of respondent *i*, can be expressed as:

$$\text{Inter}_i = f(\beta_0 + \beta_1\text{Dub}_i + \beta_2\text{Urb}_i + \beta_3\text{Age}_i + \beta_4\text{Edu}_i + \beta_5\text{Job}_i + \beta_6\text{ABC}_i + \beta_7\text{Home}_i + \beta_8\text{Nat}_i + \beta_9\text{Eth}_i + \beta_{10}\text{MigX}_i + \varepsilon_i) \tag{6.5}$$

In a similar fashion the preliminary empirical model for the broadband Internet adoption decision of respondent *i*, can be expressed as:

$$\text{Bband}_i = f(\beta_0 + \beta_1\text{Dub}_i + \beta_2\text{Urb}_i + \beta_3\text{Age}_i + \beta_4\text{Edu}_i + \beta_5\text{Job}_i + \beta_6\text{ABC}_i + \beta_7\text{Home}_i + \beta_8\text{Nat}_i + \beta_9\text{Eth}_i + \beta_{10}\text{MigX}_i + \varepsilon_i) \tag{6.6}$$

The forced entry method is the most appropriate method for theory testing in logit regression because the alternative method of stepwise techniques seldom gives replicable results (Studenmund and Cassidy, 1987). In the forced entry method all of the covariates (the predictor variables) are placed into the regression model at the same time. I use the standard forced entry method of estimation throughout to generate the functional relationships of the logit model.

Interpretation of the logit statistics requires explanation and I draw on Andy Field (2003) for much of the following section. Wooldridge (2002) identifies the Wald test as appropriate for testing hypotheses in binary response contexts. The Wald statistic tells us whether or not a predictor variable is in fact a statistically significant predictor of the outcome. Specifically, the Wald statistic tells us whether the β value (the beta coefficient) for the predictor variable is significantly different from zero and the Wald test is therefore somewhat analogous to the t-statistic used in linear regression models. Scott Menard (1995) cautions that when the β value is large the Wald statistic can become underestimated leading to a rejection of the predictor variable's statistical significance when in reality it is actually significant. In logistic regression the coefficient represents the change in the logit of the outcome variable associated with a one-unit change in the predictor variable (Field, 2003). For the purposes of this study the outcome variable of interest is the adoption decision. The logit of the outcome variable is the natural logarithm of the odds of the adoption event occurring. The exp(β) or 'odds ratio' statistic is the key to interpreting logistic regression. Exp(β) indicates the 'change' in the odds of an event occurring resulting from a unit change in the predictor variable. The odds of an event occurring is defined as the probability of an event occurring divided by the probability of the event not occurring. An exp(β) value greater than 1 indicates that the odds of the event occurring will increase when the predictor variable increases. On the other hand an exp(β) value less than 1 indicates that the odds of an event occurring will decrease as the predictor variable increases. As an example: If the probability of adoption for the control group is estimated at 50 per cent, then the odds of an event occurring before treatment are calculated as 50/50 = 1. However, if the probability of adoption for the treatment group is estimated at 80 per cent, then the odds of an event occurring after treatment are calculated as 80/20 = 4. The 'change' in the odds of an event occurring is then calculated as equal to: (odds after treatment)/(odds before treatment) which is 4/1 = 4. In this case the exp(β) or 'odds ratio' statistic is equal to 4.

The diagnostic statistics tell us whether the estimated logit model fits the data well (Wooldridge, 2002; Field, 2003). If the model fits the data well then we have confidence the coefficients and odds ratios produced by the model are reasonably accurate. According to Field (2003), the main residual diagnostic statistic for the logit model is the -2 Log Likelihood (-2LL) statistic. The log-likelihood statistic indicates how poorly the model predicts the adoption decisions. Specifically, the log-likelihood statistic is an indicator of how much unexplained information there is after the model has been fitted and therefore lower log-likelihood values indicate the model is predicting the outcome variable more accurately. The percent correctly predicted, known as the Count R^2 statistic, is a basic measure of the goodness-of-fit of a model. Unfortunately an equivalent statistic to R^2 does not exist when analysing data produced using a logistic regression (UCLA, 2011). To evaluate the goodness-of-fit of logistic models, several pseudo R^2 measures such as the Cox and Snell R^2 and the Nagelkerke R^2 have been developed. Higher values for these statistics indicate a better fitting model. Field (2003) identifies the Hosmer-Lemeshow (H-L) statistic (Hosmer and Lemeshow, 1989) as a reasonable equivalent to the R^2 value used in linear regression and as a good measure of how well the chosen model fits the data. The H-L statistic is a measure of how much the 'badness-of-fit' improves as a result of the inclusion of the predictor variables. A Hosmer-Lemeshow statistic of zero suggests the predictors are useless at predicting the outcome variable, while an H-L statistic of 1 indicates the model predicts the outcome variable perfectly (Field, 2003).

6.4 Models of Household Level Broadband Adoption in Ireland

Descriptive statistics

As a first step I subdivided the 212,005 COPSAR respondents into ten separate 21,201 subsamples. This was because of processing limitations in the analytical software used. When subdividing the sample I used systematic random sampling. One thousand respondents from each block of ten thousand respondents were placed in each subsample. One of the random subsamples was then chosen and used to estimate the impact of the predictor variables on the adoption decisions. The COPSAR dataset is itself a random sample and the subsample therefore contains a random set of respondents. Large sample sizes are generally preferred to small sample sizes because large sample sizes lead to increased precision (smaller confidence intervals) when estimating unknown parameters. However, a sample size as large as 21,201 will retain the large-sample or asymptotic properties of unbiasedness and consistency (Gujarati, 1995, p.771-72) and will generate small confidence intervals. Table 6.6 shows the frequency breakdown within the subsample for each of the variables described in Table 6.5. Over half of the sample, or 53 per cent, had an Internet subscription of any type at the time of the Census while just under a quarter of the sample, or 23 per cent, had a broadband subscription at the time of the Census. Every possible respondent characteristic occurs at least 10 per cent of the time within the sample with the exceptions of two of the four ‘recent migrant’ responses (Mig3 and Mig4).

Table 6.6: Frequency of respondent characteristics in the COPSAR subsample

Characteristic	**Frequency (%)**
Internet Access	53
Broadband Access	23
Dublin Resident	28
Urban Resident	61
Of Working Age	61
Attended Third Level	23
Working for Payment or Profit	46
ABC Socio-Economic Groups	32
Purchaser/Owner-occupier	75
Foreign Nationality	11
Foreign Ethnicity	12
Recent Migrant (1)	13
Recent Migrant (2)	11
Recent Migrant (3)	05
Recent Migrant (4)	04

The bivariate correlations are shown in Table 6.7. The Table can be read by cross referencing the two variables of interest. The HOME variable and the ABC variable are two of the three proxies for respondent income and wealth (JOB is the other one). These two variables have the strongest correlations with general Internet adoption. HOME has a .301 correlation with general Internet adoption while ABC has a .279 correlation with general Internet adoption. On the other hand, the two proxies for population density (DUB and URB) have the strongest correlations with broadband adoption. The DUB variable has a .205 correlation with broadband adoption while URB has a .250 correlation with broadband adoption. Although URB has the strongest correlation with broadband adoption it does not exhibit a statistically significantly correlation with general Internet adoption (.011). This may suggest that urban dwellers have no inherently greater awareness or preference for Internet services than rural dwellers. If so, the strength of correlation between URB and broadband adoption must reflect other factors besides awareness and preference for Internet services. Surprisingly, the three proxies for income and wealth, namely JOB, HOME, and ABC are less correlated with adoption of the more expensive broadband service, than they are with the less expensive generic Internet service. This may suggest that income and wealth are not important barriers to broadband adoption. Alternatively, the finding may suggest that the proxies are poor indicators of income and wealth. Nevertheless, correlation does not imply causation and it is impossible to draw causal interpretations at this point. The social displacement variables (MigX, NAT and ETH) do not exhibit strong correlations with either of the adoption variables. There are however strong correlations between the recent migration variables (MigX) and the non-Irish variables (NAT and ETH). In particular, the strength of the correlation between the foreign nationality and foreign ethnicity variables (.863) suggests there will be problems of multicollinearity if both variables are included in the same model specification.

Table 6.7: Bivariate correlations between the COPSAR variables

	Mig1	Mig2	Mig3	Mig4	Dub	Urb	Age	Edu	Job	Home	ABC	Nat	Eth
Inter	-.078**	-.084**	-.033**	-.040**	.061**	.011	.037**	.143**	.068**	**.301****	**.279****	-.044**	-.028**
Bband	.006	.007	.021**	.026**	**.205****	**.250****	.043**	.109**	.046**	.078**	.171**	.041**	.054**
Mig1	-	-	-	-	.033**	.087**	.049**	**.109****	.055**	**-.257****	.010	**.274****	**.279****
Mig2	-	-	-	-	.037**	.096**	.112**	.141**	.102**	**-.268****	.000	**.300****	**.299****
Mig3	-	-	-	-	.026**	.050**	-.015*	.025**	-.001	-.188**	-.016*	**.335****	**.333****
Mig4	-	-	-	-	.035**	.066**	.084**	.073**	.073**	**-.217****	-.037**	**.414****	**.401****
Dub	-	-	-	-	-	**.466****	.049**	.084**	.042**	-.100**	.054**	.069**	.080**
Urb	-	-	-	-	-	-	.057**	.084**	.033**	**-.212****	.034**	.112**	.124**
Age	-	-	-	-	-	-	-	**.357****	**.651****	-.037**	-.018**	.128**	.100**
Edu	-	-	-	-	-	-	-	-	**.354****	.011	**.303****	.094**	.092**
Job	-	-	-	-	-	-	-	-	-	.029**	.044**	.095**	.073**
Home	-	-	-	-	-	-	-	-	-	-	.195**	**-.355****	**-.356****
ABC	-	-	-	-	-	-	-	-	-	-	-	-.058**	-.050**
Nat	-	-	-	-	-	-	-	-	-	-	-	-	**.863****
Eth	-	-	-	-	-	-	-	-	-	-	-	-	-

Note: ** means correlation is significant at the 0.01 level; 21,201 cases

Main empirical findings

The univariate logit estimates for broadband Internet adoption and for general Internet adoption are presented in Table 6.8 and Table 6.9 respectively. Each of the predictor variables is individually estimated to be a statistically significant predictor of broadband Internet adoption (see Table 6.8) with the exception of two of the four MigX variables. All of the estimated odds ratios are greater than 1 suggesting the predictor variables exert positive effects on the odds of broadband adoption. The strongest effect on broadband adoption is exerted by the URB variable ($\exp(\beta) = 4.186$). This means that if the respondent is living in an urban location as opposed to a rural location the odds of broadband adoption occurring, as opposed to not occurring, will increase by a factor of over 4. URB (.066) is also the only variable to produce a Cox & Snell R^2 in excess of .05, while DUB (.059) and URB (.100) are the only variables to produce a Nagelkerke R^2 in excess of .05. The DUB variable ($\exp(\beta) = 2.726$) and the ABC variable ($\exp(\beta) = 2.282$) are the only other variables besides URB to generate an odds ratios in excess of 2.

Table 6.8: Univariate logit estimates for broadband Internet adoption

Independent Variables	Odds Ratio: exp(B)	Beta Coefficient	Wald Statistic	-2LL	Percent Correct	Cox & Snell R^2	Nagelkerke R^2
Edu	1.778	.576	247.369***	22532.251	77.2	.011	.017
ABC	**2.282**	.825	600.268***	22178.676	77.2	.028	.042
Dub	**2.726**	1.003	854.868***	21932.164	77.2	.039	**.059**
Urb	**4.186**	1.432	1193.617***	21323.956	77.2	**.066**	**.100**
Home	1.582	.459	128.305***	22635.548	77.2	.006	.010
Mig1	1.044	.043	.780	22770.405	77.2	.000	.000
Mig2	1.055	.053	1.096	22770.093	77.2	.000	.000
Mig3	1.239	.214	9.233***	22672.227	77.2	.000	.001
Mig4	1.361	.308	14.261***	22757.519	77.2	.001	.001
Age	1.240	.215	39.769***	22730.945	77.2	.002	.003
Job	1.243	.218	44.050***	22727.161	77.2	.002	.003
Nat	1.339	.292	36.152***	22736.233	77.2	.002	.003
Eth	1.446	.369	60.605***	22712.958	77.2	.003	.004

Note: $^{***}p<0.01$; $^{**}p<0.05$; $^{*}p<0.10$, percent correct with constant is 77.2%

By contrast, the URB variable is the only predictor variable not estimated to be a statistically significant predictor of general Internet adoption (see Table 6.9). This is shown by the Wald statistic for URB which indicates that the odds of general Internet adoption occurring, versus not occurring, is unrelated to whether the respondent is living in an urban or a rural location. It appears that recent migration and non-Irish ethnicity are associated with reduced odds of general Internet adoption. The strongest effect on general Internet adoption is exerted by the nature of occupancy variable (HOME) which has an odds ratio over 4 ($\exp(\beta) = 4.285$). This suggests that the odds of general Internet adoption occurring, as opposed to not occurring, will increase by a factor of over 4 where the respondent is living in purchaser/owner-occupied accommodation as opposed to living in rental or other accommodation. The socio-economic status variable ABC ($\exp(\beta) = 3.575$) and the education variable EDU ($\exp(\beta) = 2.027$) are the only other predictor variables with estimated odds ratios in excess of 2. The HOME variable and the ABC variable are the only variables to produce Cox and Snell R^2 values greater than .05 and the only variables to produce a Nagelkerke R^2 values greater than .10.

Table 6.9 Univariate logit estimates for general Internet adoption

Independent Variables	Odds Ratio: exp(B)	Beta Coefficient	Wald Statistic	-2LL	Percent Correct	Cox & Snell R^2	Nagelkerke R^2
Edu	**2.027**	.707	426.751***	28861.217	54.3	.021	.026
ABC	**3.575**	1.274	1569.458***	27596.970	61.9	**.077**	**.103**
Dub	1.313	.272	78.230***	29225.963	53.2	.004	.005
Urb	1.046	.045	2.571	29302.107	53.2	.000	.000
Home	**4.285**	1.455	1771.262***	27347.385	64.6	**.088**	**.118**
Mig1	.626	-.468	128.360***	29174.931	55.0	.006	.008
Mig2	.589	-.529	145.700***	29156.683	55.1	.007	.009
Mig3	.744	-.295	22.432***	29282.164	53.6	.001	.001
Mig4	.650	-.431	33.767***	29270.495	53.7	.002	.002
Age	1.163	.151	28.520***	29276.155	53.2	.001	.002
Job	1.313	.273	96.683***	29207.712	53.2	.005	.006
Nat	.758	-.277	41.233***	29263.358	53.9	.002	.003
Eth	.842	-.172	16.365***	29288.317	53.3	.001	.001

Note: $^{***}p<0.01$; $^{**}p<0.05$; $^{*}p<0.10$, percent correct with constant only is 53.2%.

It is perhaps surprising that the predictor variable estimated to have the strongest influence on the odds of broadband adoption is also the only variable estimated to have no statistically significant effect on the odds of general Internet adoption. This is illustrated more clearly in Table 6.10 where I compare the Wald statistics for each of the predictor variables ranked by order of significance. The URB variable has the largest Wald statistic for broadband adoption yet the smallest Wald statistic for general Internet adoption.

Table 6.10: Comparison of Wald statistics for the predictor variables

	Broadband		**General Internet**	
Rank	**Variable**	**Wald Statistic**	**Variable**	**Wald Statistic**
1	**Urb**	1193.617***	Home	1771.262***
2	Dub	854.868***	ABC	1569.458***
3	ABC	600.268***	Edu	426.571***
4	Edu	247.369***	Mig2	145.700***
5	Home	128.305***	Mig1	128.360***
6	Eth	60.605***	Job	96.683***
7	Job	44.050***	Dub	78.230***
8	Age	39.769***	Nat	41.233***
9	Nat	36.152***	Mig4	33.767***
10	Mig4	14.261***	Age	28.520***
11	Mig3	9.233***	Mig3	22.432***
12	Mig2	1.096	Eth	16.365***
13	Mig1	.780	**Urb**	2.571

Note: Significance of Wald Statistic: ***$p<0.01$; **$p<0.05$; *$p<0.10$.

The estimated odds ratios for a selection of the multivariate logit models of broadband adoption are reported in Table 6.11. The first model shown (Model-BA) includes the URB variable as the univariate logit estimates suggest that URB has the greatest explanatory power over broadband adoption decisions. The subsequent models (Model-BB through to

Model-BI) show the added effects of including additional variables in the multivariate model. The variables included in the models shown here are added in the order suggested by the univariate estimates. Note that the NAT variable is dropped from the analysis because of multicollinearity issues with the ETH variable. The ETH variable is retained because it has a larger Wald statistic than NAT. Also note that only the MigX specification with the largest Wald statistic is included in the model specification (Mig4).

I use the Hosmer-Lemeshow test (H-L) to compute a χ-square statistic for each model. This compares the observed frequencies with the frequencies expected under the linear model. A non-significant χ-square indicates that the data fit the model well. Model-BB, which includes the URB and DUB variables, has a non-significant χ-square (1.000). The Hosmer-Lemeshow value of 1 implies that the model predicts the outcome variable perfectly. The Cox & Snell R^2 of Model-BB is .074 while the Nagelkerke R^2 is .112. In Model-BB the urban variable (URB) has an odds ratio above 3 ($\exp(\beta) = 3.342$) while the Dublin variable (DUB) has an odds ratio of 1.653. As shown in Model-BD, adding the socio-economic (ABC) and education (EDU) variables to the model specification actually causes the model to lose some ability to predict the outcome variable. However the predictive power of the model is restored when the nature of occupancy (HOME) and ethnicity (ETH) variables are subsequently added to the model. The significance of the job status variable (JOB) is found to be rejected while the additions of the working age variable (AGE) and the recent migration variable (MIG4) both fail to add to the predictive power of the model. This suggests that the influence of these variables on the broadband adoption decision is negligible. Although the EDU variable exerts a statistically significant effect on broadband adoption, its contribution to the predictive power (goodness-of-fit) of the model is negligible. Adding education to the model only improves the Cox & Snell R^2 of the model from .097 to .098 and the Nagelkerke R^2 of the model from .148 to .150.

Table 6.11: Model estimates of the odds ratios for broadband adoption

	Model BA	Model BB	Model BC	Model BD	Model BE	Model BF	Model BG	Model BH	Model BI
Urb	4.186 (1.432)***	3.342 (1.207)***	3.406 (1.225)***	3.373 (1.216)***	3.755 (1.323)***	3.748 (1.321)***	3.747 (1.321)***	3.743 (1.320)***	3.742 (1.320)***
Dub	-	1.653 (.502)***	1.609 (.476)***	1.596 (.467)***	1.617 (.481)***	1.607 (.474)***	1.606 (.474)***	1.605 (.473)***	1.606 (.474)***
ABC	-	-	2.279 (.824)***	2.150 (.765)***	1.889 (.636)***	1.908 (.646)***	1.916 (.650)***	1.935 (.660)***	1.938 (.662)***
Edu	-	-	-	1.235 (.211)***	1.276 (.244)***	1.225 (.203)***	1.200 (.182)***	1.175 (.161)***	1.172 (.158)***
Home	-	-	-	-	1.921 (.653)***	2.310 (.837)***	2.305 (.835)***	2.312 (.838)***	2.334 (1.432)***
Eth	-	-	-	-	-	1.803 (.589)***	1.798 (.587)***	1.791 (.583)***	1.724 (.545)***
Job	-	-	-	-	-	-	1.047 (.046)	.986 (-.014)	.984 (-.016)
Age	-	-	-	-	-	-	-	1.111 (.105)**	1.109 (.104)**
Mig4	-	-	-	-	-	-	-	-	1.208 (.189)**
H-L (sig)	-	1.000	.054	.000	.339	.538	.045	.059	.033
-2LL	21323.956	21145.909	20600.589	20573.830	20336.005	20226.070	20224.602	20220.156	20216.000
CS R^2	.066	.074	.097	.098	.109	.113	.113	.113	.114
Nk R^2	.100	.112	.148	.150	.165	.172	.172	.172	.172
Per	77.2	77.2	77.2	77.0	77.3	77.3	77.3	77.4	77.3

Note: Beta coefficients are shown in brackets. Significance of Wald statistic: $^{***}p<0.01$; $^{**}p<0.05$; $^{*}p<0.10$. Number of observations = 21,201, H-L = the Hosmer Lemeshow statistic, CS R^2 = the Cox & Snell R^2, Nk R^2 = the Nagelkerke R^2, Per. = the percentage of correct predictions

In Table 6.12 I again show four of the model specifications reported in Table 6.11 but this time also include three additional model specifications – these are Model-BJ, Model-BK and Model-BL. These three models exclude the poorly predicting education (EDU) variable.

Adding nature of occupancy (HOME) to the model instead of EDU provides a better fit in terms of ability to correctly predict the adoption outcome (see Model-BJ). Model-BJ is the model with the best ability to correctly predict broadband adoption outcomes successfully predicting the decision 77.6 per cent of the time. Adding the ethnicity and education variables to the model (Model-BF) reduces the percentage of successful predictions. In Model-BJ the urban variable (URB) displays the highest odds ratio with an exp(β) of 3.789, this is followed by the socio-economic variable ABC with an exp(β) of 2.024, then the nature of occupancy variable HOME (exp(β) = 1.896), and finally the Dublin region variable DUB (exp(β) = 1.631)

Table 6.12: Odds ratios for broadband adoption

	Model BB	Model BD	Model BE	Model BF	Model BJ	Model BK	Model BL
Urb	3.342 (1.207)***	3.373 (1.216)***	3.755 (1.323)***	3.748 (1.321)***	3.789 (1.332)***	4.714 (1.551)***	4.220 (1.440)***
Dub	1.653 (.502)***	1.596 (.467)***	1.617 (.481)***	1.607 (.474)***	1.631 (.489)***	-	-
ABC	-	2.150 (.765)***	1.889 (.636)***	1.908 (.646)***	2.024 (.705)***	2.056 (.721)***	2.310 (.837)***
Edu	-	1.235 (.211)***	1.276 (.244)***	1.225 (.203)***	-	-	-
Hom	-	-	1.921 (.653)***	2.310 (.837)***	1.896 (.640)***	1.874 (.628)***	-
Eth	-	-	-	1.803 (.589)***	-	-	-
H-L (sig)	1.000	.000	.339	.538	.286	.072	.003
-2LL	21145.909	20573.830	20336.005	20226.070	20531.287	20531.287	20754.597
CS	.074	.098	.109	.113	.107	.100	.091
Nk	.112	.150	.165	.172	.163	.152	.138
Per	77.2	77.0	77.3	77.3	77.6	77.2	77.2

Note: Beta coefficients are shown in brackets. Significance of Wald statistic: $^{***}p<0.01$; $^{**}p<0.05$; $^{*}p<0.10$. Number of observations = 21,201, H-L = the Hosmer Lemeshow statistic, CS R^2 = the Cox & Snell R^2, Nk R^2 = the Nagelkerke R^2, Per = The percentage of correct predictions

Table 6.13 reports the odds ratios for selected multivariate logit models of general Internet adoption. The first model shown, (Model-IA), only includes the HOME variable as the univariate logit estimates suggest that HOME has the greatest explanatory power over general Internet adoption decisions. The subsequent models (Model-IB through to Model-II) show the added effects of including additional variables in the multivariate model. As with the broadband adoption models, the variables included in the models shown here are added in the order suggested by the univariate estimates. While the URB variable does not have a significant Wald statistic in the univariate model I nevertheless include the URB variable in Model-II for the purpose of completeness. Note that the ethnicity variable ETH is dropped because of multicollinearity issues with the nationality variable NAT. The NAT variable is retained because it has a larger Wald statistic than ETH. Also note that only the MigX specification with the largest Wald statistic is retained. This is Mig2. Model-IB, which contains just the nature of occupancy (HOME) and the socio-economic group (ABC) variables, has a non-significant Hosmer-Lemeshow. The χ-square is .662. This suggests the model predicts the outcome variable well. The Cox & Snell R^2 of the model is .138 while the Nagelkerke R^2 is .184. In Model-IB the HOME variable has an odds ratio greater than 3 ($\exp(\beta) = 3.651$), as does the ABC variable ($\exp(\beta) = 3.034$). Adding the education variable EDU to the model causes it to lose its ability to predict the outcome variable and the Hosmer-Lemeshow badness-of-fit statistic falls to .000.

Table 6.13: Model estimates of the odds ratios for general Internet adoption

	Model IA	Model IB	Model IC	Model ID	Model IE	Model IF	Model IG	Model IH	Model II
Hom	4.285 (1.455)***	3.651 (1.295)***	3.776 (1.319)***	3.624 (1.287)***	3.597 (1.280)***	3.793 (1.333)***	4.308 (1.460)***	4.313 (1.462)***	4.417 (1.485)***
ABC	-	3.034 (1.110)***	2.695 (.991)***	2.702 (.994)***	2.735 (1.006)***	2.698 (.992)***	2.728 (1.004)***	2.742 (1.009)***	2.731 (1.005)***
Edu	-	-	1.574 (.453)***	1.612 (.478)***	1.522 (.420)***	1.489 (.398)***	1.459 (.378)***	1.445 (.368)***	1.439 (.364)***
Mg2	-	-	-	.806 (-.216)***	.795 (-.230)***	.794 (-.230)***	.715 (-.335)***	.715 (-.336)***	.710 (.-342)***
Job	-	-	-	-	1.148 (.138)***	1.140 (.131)***	1.120 (.113)***	1.088 (.084)**	1.089 (.085)**
Dub	-	-	-	-	-	1.456 (.376)***	1.444 (.368)***	1.443 (.367)***	1.352 (.302)***
Nat	-	-	-	-	-	-	1.689 (.524)***	1.684 (.521)***	1.679 (.518)***
Age	-	-	-	-	-	-	-	1.052 (.050)	1.049 (.048)
Urb	-	-	-	-	-	-	-	-	1.143 (.134)***
H-L (sig)	-	.662	.000	.000	.000	.000	.000	.000	.000
-2LL	27347.385	26161.227	26019.301	26001.216	25982.600	25860.367	25764.776	25763.304	25748.873
CS	.088	.138	.144	.144	.145	.150	.154	.154	.154
Nk	.118	.184	.1 92	.193	.194	.200	.205	.205	.206
Per	64.6	64.6	64.5	64.7	64.7	66.9	66.9	67.0	66.3

Note: Beta coefficients are shown in brackets. Significance of Wald statistic: $^{***}p<0.01$; $^{**}p<0.05$; $^{*}p<0.10$. Number of observations = 21,201. H-L = the Hosmer Lemeshow statistic, CS = the Cox & Snell R^2, Nk = the Nagelkerke R^2, Per = The percentage of correct predictions

Table 6.14 reports the effects of adding additional variables to Model-IB. The geographic location variables (DUB) and (URB) are found to be the only additions that produce well-fitting models (see Model-IO and Model-IP). However, adding both of the location variables is less effective at predicting the adoption decision than merely adding the URB variable by itself. Thus despite the univariate model showing urban residency to be non-statistically significant, the URB variable does appear to contribute to the predictive power of the multivariate model.

Table 6.14: Odds ratios for general Internet adoption

	Model IB	Model IJ	Model IK	Model IL	Model IM	Model IN	Model IO	Model IP
Hom	3.651 (1.295)***	3.562 (1.270)***	3.652 (1.295)***	3.870 (1.353)***	4.256 (1.448)***	3.704 (1.309)***	3.944 (1.372)***	3.984 (1.382)***
ABC	3.034 (1.110)***	3.050 (1.115)***	3.010 (1.102)***	2.971 (1.089)***	3.038 (1.111)***	3.052 (1.116)***	2.979 (1.092)***	2.954 (1.083)***
Mg2	-	.884 (-.124)**	-	-	-	-	-	-
Job	-	-	1.265 (.235)***	-	-	-	-	-
Dub	-	-	-	1.493 (.400)***	-	-	-	1.387 (.327)***
Nat	-	-	-	-	1.705 (.534)***	-	-	-
Age	-	-	-	-	-	1.273 (.242)***	-	-
Urb	-	-	-	-	-	-	1.332 (.287)***	1.162 (.150)***
H-L (sig)	.662	.000	.000	.191	.017	.000	.323	.297
-2LL	26161.227	26155.041	26099.297	26020.685	26054.059	26098.753	26076.187	26002.308
CS	.138	.138	.140	.143	.142	.140	.141	.144
Nk	.184	.184	.187	.192	.190	.187	.189	.193
Per	64.6	64.8	64.4	64.8	64.7	65.6	66.9	65.3

Note: Beta coefficients are shown in brackets. Significance of Wald statistic: $^{***}p<0.01$; $^{**}p<0.05$; $^{*}p<0.10$. Number of observations = 21,201. H-L = the Hosmer Lemeshow statistic, CS = the Cox & Snell R^2, Nk = the Nagelkerke R^2, Per = The percentage of correct predictions

Interpretation of the empirical results

How do we interpret the empirical results? I present selected parsimonious models of broadband adoption and general Internet adoption in Table 6.15 and in Table 6.16 respectively. I find that the urban residency variable exerts the strongest impact on the odds of a broadband adoption event occurring (see Table 6.15). Specifically, the odds of a respondent having a broadband subscription increases by a factor of over 3 where the respondent is living in an urban location as opposed to a rural location. In addition, I estimate that being located in Dublin; being a member of the managerial and professional socio-economic group; and being resident in purchaser/owner-occupier accommodation, are all associated with increased odds of broadband adoption compared to respondents without these characteristics. Therefore the results suggest that the probability of a respondent adopting broadband in Ireland in 2006 was influenced by the respondent’s geographic location as well as by the respondent’s financial capacity – at least to the extent that the HOME and ABC variables are appropriate as proxies for income and wealth. There does appear to some evidence of educational attainment influencing broadband adoption. However, if we compare the goodness-of-fit statistics for Model-BJ and Model-BE (see Table 6.12) we find that the addition of the education variable has a negative marginal effect on the predictive power of the model and has a negligible marginal effect on the goodness-of-fit. The job status, age and recent migration variables all fail to enhance the predictive power of the model. The finding for the job status variable is particularly surprising as I would have expected job status to be highly correlated with income and therefore with capacity to purchase a broadband subscription. One possible explanation is that those in employment or self-employed may already have access to the Internet in their work place, thereby reducing the net utility of having broadband access at home. Finally, there is some evidence that non-Irish ethnicity ETH is positively associated with broadband adoption. This may reflect greater social displacement and preference for long-distance communication because respondents from non-Irish groups may on average be more geographically separated from their social network.

Table 6.15: Parsimonious models of broadband Internet adoption

Independent Variable	**Model-BB**	**Model-BC**	**Model-BJ**
Resides in an Urban location	**3.342** [3.059 to 3.650] (1.207)	**3.406** [3.115 to 3.724] (1.432)	**3.789** [3.460 to 4.148] (1.332)
Resides in the Dublin region	**1.653** [1.535 to 1.779] (.502)	**1.609** [1.492 to 1.734] (.476)	**1.631** [1.512 to 1.760] (.489)
Member of a professional/managerial socio-economic group	-	**2.279** [2.128 to 2.442] (.824)	**2.024** [1.886 to 2.172] (.705)
Resides in a purchaser/owner-occupied home	-	-	**1.896** [1.741 to 2.064] (.640)
Constant	.107 (-2.33)	.079 (-2.542)	.047 (-3.064)
Hosmer-Lemeshow (sig)	1.000	.054	.286
-2LL Log Likelihood	21145.909	20600.589	20531.287
Cox & Snell R^2	.074	.097	.107
Nagelkerke R^2	.112	.148	.163
Percentage correct	77.2	77.2	77.6

Note: Odds ratios are in bold. Ninety five per cent Confidence Intervals for the odds ratios exp(β), are in square brackets). Beta coefficients are in round brackets. All Wald statistics are significant at the <0.01 level. Number of observations = 21,201.

While the geographic location variables are found to exert the greatest influence on the respondent's odds of having a broadband subscription - it is the nature of occupancy variable (HOME) which exerts the greatest influence on the respondent's odds of having an Internet subscription of any kind. Specifically, I find that the odds of a respondent having an Internet subscription increase by a factor of over 3 where the respondent is living in purchaser/owner-occupied accommodation as opposed to living in rental or other accommodation. The next strongest influence on the odds of having an Internet subscription is exerted by the socio-economic (ABC) variable. Respondents from the managerial and professional socio-economic group are approximately 3 times more likely to have Internet access of some kind than respondents from other socio-economic groups. Urban residency and Dublin residency both appear to increase the odds of Internet adoption but contribute very little to the explanatory power of the model. Inclusion of the Dublin variable actually reduces the predictive power (percentage correct) of the model. Thus while geographic location appears to exert the strongest influence on broadband adoption it appears that the wealth and income proxies exert the strongest influence on general Internet adoption.

Table 6.16: Parsimonious models of general Internet adoption

Independent Variable	Model-IB	Model-IO	Model-IP
Resides in a purchaser/owner-occupied home	**3.651** [3.406 to 3.915] (1.295)	**3.944** [3.670 to 4.237] (1.372)	**3.984** [3.707 to 4.282] (1.382)
Member of a managerial/professional socio-economic group	**3.034** [2.843 to 3.239] (1.110)	**2.979** [2.791 to 3.180] (1.092)	**2.954** [2.767 to 3.153] (1.083)
Resides in an Urban location	-	**1.332** [1.253 to 1.416] (.287)	**1.162** [1.085 to 1.244] (.150)
Resides in the Dublin region	-	-	**1.387** [1.287 to 1.494] (.327)
Constant	.306 (-1.183)	.245 (-1.407)	.241 (-1.421)
Hosmer-Lemeshow (sig)	.662	.323	.297
-2LL Log Likelihood	26161.227	26076.187	26002.308
Cox & Snell R^2	.138	.141	.144
Nagelkerke R^2	.184	.189	.193
Percentage correct	64.6	66.9	65.3

Note: Odds ratios are in bold. Ninety five per cent Confidence Intervals for the odds ratio exp(β) are in square brackets). Beta coefficients are in round brackets. All Wald statistics are significant at the <0.01 level. Number of observations = 21,201.

What inferences can we draw from the findings? It may be useful at this point to recall the Table 6.2 framework of questions underpinning consumer's technology adoption decisions. Physical location, (geographic location) is likely to act on the respondent's opportunity to acquire the technology. On the other hand, income and wealth are likely to act primarily on the respondent's capacity to acquire the technology. The results suggest that the income and wealth proxies exert greater influence on the odds of general Internet adoption than they do on the odds of broadband specific Internet adoption. This is notable because broadband Internet access is almost invariably at least as expensive if not more expensive than dial-up Internet access. The relatively weak ability of the wealth and income proxies to improve the performance of the broadband adoption model suggests that the broadband adoption decision is only partially attributable (if at all) to the increased capacity of wealthier respondents to purchase broadband Internet services.

Most important for broadband adoption are the geographic location variables. The geographic location variables have a stronger influence on the odds of broadband Internet adoption than they do on the odds of general Internet adoption. This is in accordance with expectations given that general Internet access was more widely available in 2006 than broadband Internet access. Dublin residency improves the odds of broadband adoption above and beyond urban residency. This suggests comparatively high odds of adoption in Dublin, followed by the other urban areas, and with rural areas having the lowest odds of adoption. This finding is consistent with the pattern of diffusion of broadband availability in Ireland. On the other hand the diagnostic statistics for the Internet adoption models suggest that the geographic location variables only very weakly contribute to the goodness-of-fit of the model. One interpretation of this result is that rural and non-Dublin residents do not appear to display a relative lack of awareness or revealed preference for Internet services where Internet services are available to purchase. Therefore as broadband access principally offers improved but quite similar functionality to the service offered by narrowband access, it seems unlikely that rural residents would display a particular lack of preference for broadband if it were available for them to purchase. The findings do not mean that awareness and preference related reasons are of no relevance to the broadband adoption decisions of Irish householders. Nevertheless, alongside capacity issues associated with wealth and income, I propose that it was a lack of opportunity to adopt broadband services, as opposed to lack of awareness of broadband, or lack of preference for broadband, that was the main factor inhibiting household specific broadband adoption in Ireland in 2006.

6.5 Conclusion

Do the results have any implications for broadband policy in Ireland? The results appear to corroborate the finding from chapter four that financial capacity matters for broadband adoption. However, Ireland is a comparatively high income country by OECD standards and it is therefore unclear why lack of financial capacity would disproportionately constrain broadband penetration in Ireland compared to the OECD. Of greater interest therefore is the inference drawn that lack of availability and opportunity is the main reason behind Ireland’s weak broadband diffusion. The implication is that Ireland’s broadband policy would be better off focused on reducing barriers to providing broadband services and reducing the costs of broadband service provision, particularly in non-urban areas, than it would focused on policies designed to stimulate residential broadband demand, for example through public awareness campaigns, or on measures designed to increase the net benefit of broadband adoption, for example by subsidising purchases of broadband services.

Chapter Seven: Concluding Thoughts on Broadband in Ireland, Past, Present and Future

7.1 Introduction

In chapter two I made the case for broadband's importance to long-run economic growth and in chapter three I showed that Ireland's broadband indicators were very weak compared to the peer group of other advanced economies. How can we explain Ireland's historical lack of success when it comes to broadband and what are the implications for the future? The economy is a highly complex; dynamic, and adaptive system. It is characterised by multiple equilibria and heterogeneous interacting agents, and these interactions are usually non-linear and context dependent (Haldane, 2012). We therefore cannot say with complete authority why markets and outcomes developed in the way they did in Ireland. However, this does not preclude us from drawing tentative conclusions. Our economic conclusions must be rooted in some economic theory and in some underlying structure to inform us. The appropriate criterion for assessing the validity of our theories is the degree of empirical corroboration. Within this context, my empirical contributions offer some insights to help improve our understanding of what occurred in Ireland, and help improve our ability to predict future developments.

7.2 Empirical Contributions

I make a number of empirical contributions. In chapter four I contribute by testing a series of hypotheses related to the international variation in broadband penetration. I find over 83 per cent of the international variation in broadband penetration is explained by a combination of countries different start-dates for the broadband diffusion process, and countries differing sets of non-policy related socio-economic, demographic and vintage infrastructure endowments. The OLS estimates show that higher diffusion levels of Internet subscription and telephone mainline in 2000 are statistically significant predictors of higher broadband penetration in later years. This suggests that broadband penetration is positively influenced by the prior diffusion of vintage telecommunications infrastructure. My results also suggest that a delay in the start of the diffusion process has a negative effect on the level of diffusion in later years. Higher levels of population density and population concentration are also statistically significant predictors of higher broadband penetration. These findings support the hypothesis that unfavourable demographic conditions inhibit the diffusion and quality of network infrastructure. I also find that third level education is a statistically significant predictor of broadband penetration. This result supports the hypothesis that there is a positive relationship between human capital and ICT adoption. However, my main contribution in chapter four is an analysis of Ireland's broadband performance relative to the rest of the OECD (see Table 4.16) and the compilation of a league table of broadband efficiency scores for OECD countries (see Table 4.15). The league table identifies the countries' most efficiently transforming their national endowment inputs into broadband subscription outputs. My results suggest that Luxembourg, Iceland, Finland and Norway are the best performing countries in the OECD. Finally, I conclude that Ireland is indeed underperforming relative to the OECD, and that Ireland's relatively weak endowment set is unable to fully account for Ireland's low rate of broadband subscription.

In chapter five I contribute by considering the counterfactual of state ownership of the telephone network infrastructure in the 21st century. Although the counterfactual is of course unknowable, I argue that the state's investment behaviour during the seventy five years of state ownership offers clues to the state's likely investment behaviour in the 21st century. Applying Goldsmith's Perpetual Inventory Method to over sixty years of price and investment data, I construct a series of datasets, which collectively describe the annual telecommunications capital additions and levels of capital depreciation between 1922 and 1997, decomposed into their transportable and non-transportable components. My analysis shows that investment in the telecommunications network appears to have been stop-start, pro-cyclical, and highly reliant on the underlying strength of the economy. The estimates suggest that the provision of telephone services was not a priority of government throughout most of the 20th century. Therefore the experience of investment levels in the 20th century does not support the hypothesis that total investment in broadband infrastructure in the early 21st century would have been given greater priority if the network had been under state control. I conclude that supply-side issues related to the weak commercial viability of telecommunications infrastructure provision in Ireland, particularly outside of urban areas, may be a factor connecting low levels of investment in the 20th and 21st centuries.

There are a number of empirical and theoretical contributions in chapter six. I propose a new conceptual framework for technology adoption (see Table 6.2) which segments reasons for non-adoption into four categories. These categories are awareness, opportunity, capacity and perceived utility. I then use this conceptual framework as a device to explain differences in broadband adoption of Irish householders, and to explain why Ireland might have weak broadband penetration outcomes. I use a discrete choice logit model to investigate the relationships between a set of census questionnaire variables, and broadband Internet and general Internet outcomes. The model estimates show that geographic location variables and wealth related variables are the variables of greatest relevance to broadband adoption decisions. Overall, the results appear to confirm that financial capacity influences the broadband adoption decision. However, Ireland is wealthier than the OECD average which suggests that lack of wealth is not responsible for Ireland's weak broadband outcomes. There is also some evidence that education is relevant to broadband adoption patterns, although as Ireland has relatively good education indicators, this is not a persuasive explanation for Ireland's weak broadband outcomes. The most important contribution in chapter six relates to the geographic location variables. The respondent's geographic location strongly influences the odds of residential broadband adoption, with Dublin and other urban locations associated with improved odds of adoption. However, the respondent's geographic location only very weakly influences the odds of general Internet adoption. One implication is that when Internet access is available to purchase, rural and non-Dublin residents do not display a particular lack of awareness or revealed preference for Internet services. Given the highly similar functionalities of broadband Internet and general Internet access in 2006, I propose that the importance of the geographic location variables is mainly a function of differences in availability as opposed to differences in consumer awareness or consumer preference. Given Ireland's relatively low population density and high population dispersion, I conclude that supply-side issues leading to poor availability in low density areas, rather than demand-side issues related to consumer preference, are responsible for Ireland's relatively weak broadband outcomes compared to the OECD.

7.3 What have we learned?

There is an historical pattern of telecommunications underdevelopment

Ireland's broadband diffusion has been slow compared to the OECD and has been particularly slow when compared to other Western European countries. The quality of broadband services has also been poor in terms of price, speed, availability and reliability. Such developments are entirely in keeping with Ireland's long term historical trend of weak telecommunications market development. The diffusion of the earliest Internet access technologies in the 1990s also trailed the OECD, while, the diffusion of the telephone network; the penetration of telephone landlines, and the quality of telephone services all lagged the rest of Western Europe for an entire century following the introduction of the telephone to Ireland in 1880. The history of relative backwardness has been maintained whether Ireland was part of the British Empire or an independent state, and has been maintained whether the network infrastructure has been under public control, as it was from 1912 to 1999, or under private control, as it was from 1880 to 1912; and from 1999 to the present day. Although Ireland was a low income country by Western European standards for much of its recent history, the diffusion of Internet technologies occurred during a period when Ireland had very high rates of per capita income and extremely fast economic growth. In addition, education levels in Ireland have historically been relatively high, so education related barriers to technology diffusion are unlikely to have been disproportionately large in Ireland.

Criticisms of Irish broadband policy may be somewhat overstated

The National Telephone Company first secured monopoly control of the network infrastructure in 1889 through its policy of buying out its commercial rivals one-by-one. The telecommunication network infrastructure has remained under effective monopoly control ever since. The government's decision to privatise the network in 1999 has been widely criticised. Much of this criticism stems from Eircom's relative lack of investment in its network infrastructure; particularly during the critical period between 2002 and 2004 when broadband was first emerging in Ireland. The argument is that this lack of investment delayed the start of the diffusion process in Ireland and stunted the development of broadband infrastructure. As discussed in chapter three the investment levels do appear to have been low and to have been inconsistent with a significant upgrade of the network infrastructure. Nonetheless, the private sector can only be expected to invest if it perceives a sufficient return on its investment. Ireland's highly dispersed and sparse population undermines the commercial case for investing in network infrastructure because it reduces the financial returns on investment. We cannot know what would have happened under the counterfactual of state control. The capital stock estimates produced in chapter five show that annual levels of investment under state ownership were inconsistent and 'stop-start' from year-to-year. The estimates illustrate that investment in the state's network infrastructure was vulnerable to prevailing economic conditions and the size and quality of the state owned infrastructure during the twentieth century appears to have been a function of the capacity of the state to invest. The relatively weak state of Ireland's telecommunications infrastructure was consistent with Ireland's traditional status as one of the poorest countries in Western Europe. Therefore we can see that inconsistent investment patterns were not confined to the Eircom era.

A second criticism of Irish broadband policy is the perceived failure of the telecommunications regulator Comreg to properly regulate Eircom, for example, by forcing Eircom as owner and operator of the main network infrastructure, to open its network to competition by way of Local Loop Unbundling (LLU). However, as discussed in chapter three, although there are certainly short-term benefits to consumers from greater competition, it is not wholly clear why forcing the incumbent operator to open up its network infrastructure in this way is the optimal long-term strategy. Forcing the network owner to open up its network to competition through LLU reduces the incumbent's incentive to invest in upgrading the network infrastructure. This is because the network owner will reap less benefit from future investment. Therefore strong LLU requirements may have a negative impact on the long-term development of broadband infrastructure. For similar reasons, an actual or perceived constraint on the ability of the network operator to freely set its own prices in the future will reduce the expected benefits of future investment. This also has negative implications for long-run investment levels. Short-run gains obtained from greater intra-platform competition in the DSL market must therefore be carefully balanced against the need for long-term investment. Universal service requirements are a second type of regulatory policy with potentially counterproductive outcomes. Universal service requirements oblige broadband providers to supply low population density areas of dubious commercial viability. This places an additional burden on providers of broadband services and the additional cost might even force broadband operators out of the market altogether. This is a particular concern given Ireland's already somewhat unattractive nature as a location for investment. The point here is not necessarily to argue that the regulator should abandon policies such as local loop unbundling and universal service requirements, merely to say that the potential benefits of these policies should be carefully balanced against long-term investment and competition considerations. It turns out that a number of non-policy reasons can help explain Ireland's pattern of relatively slow telecommunications market development.

Path dependence matters

Although Ireland is now a high income country, by Western European standards Ireland had a relatively low annual output per capita until the 1990s. The resultantly small stock of accumulated wealth may have had a negative influence on the development of the network infrastructure over time. The broadband market has its roots in earlier telecommunications markets and by and large broadband technology uses the same network infrastructure as vintage (i.e. pre broadband) telecommunication technologies. Once a country's network infrastructure falls behind it then requires additional investment just to catch-up. In the cross country study in chapter four we saw that higher rates of diffusion of earlier telecommunication technologies at the time of broadband take-off are associated with subsequently higher rates for broadband penetration. The inconsistent priority given to the network infrastructure in the twentieth century may have had knock-on effects in the twenty first century.

Overall broadband diffusion within OECD countries has broadly followed the expected S-shaped diffusion curve. However, the starting date for broadband diffusion varies from country to country. Broadband first emerged in Canada in 1997 and had begun to take off in fourteen OECD countries prior to 2000. Yet it was not until 2002 that broadband first emerged in Ireland. Broadband penetration rates in the OECD increased annually by an average of 3 to 4 subscriptions per 100 persons during the period leading up to 2008. Countries with a head start have tended to maintain their broadband advantage over time. Ireland’s relatively poor broadband outcomes should be understood in this context and are in part a consequence of the delayed emergence of broadband in Ireland. The results of the cross country study indicate that the rate of broadband diffusion was influenced by the prior diffusion of telephone mainlines and dial-up Internet. Following two decades of convergence Ireland’s telephone penetration had reached average OECD levels by 2000. However, Ireland’s Internet subscription rate was just 73 per cent of the OECD median in 2000 and just one third of the rate prevailing in Denmark at that time. The results of the cross country study indicate that each percentage point increase in a country’s Internet subscription rate in 2000 increases the country’s subsequent broadband subscription rate by between 0.3 and 0.5 percentage points. Based on the model coefficients I estimate that Ireland’s weaker than average dial-up Internet penetration in 2000 reduced Ireland’s broadband penetration rate in 2008 by 1.3 to 2.2 percentage points. Path dependence appears to matter and the negative outcomes that arise from falling behind in terms of telecommunications infrastructure can persist over time.

Demographics also appear to matter

Ireland’s population is small, geographically dispersed and of low overall density by OECD standards. Such demographic characteristics make Ireland a relatively expensive location in terms of the required capital investment per potential customer. The chapter four and chapter six results both support the hypothesis that high population density positively effects broadband diffusion and adoption. However, the results of the cross country study suggest that population density is of limited substantive importance for broadband penetration. The estimated effect size is just 1.2 to 1.8 additional broadband subscriptions for every 100 extra persons per square kilometre. Thus the gap between Ireland's population density and the OECD median reduced Ireland's penetration rate, in a given year, by just 0.6 to 0.8 percentage points. However, the cumulative effect of higher population density may be very substantial in some countries. According to the cross country estimates the difference between South Korea's high population density and the median population density in the OECD added 4.6 to 7.0 percentage points to South Korea's penetration rate. Overall the results of both studies suggest that more geographically concentrated and more urban based populations are associated with higher levels of broadband adoption. However, the cross country results indicate that the effect size of greater population concentration is not very substantive. The difference between Ireland and the OECD is estimated to have constrained Ireland's penetration rate by just 0.3 to 0.6 percentage points.

According to the results of the household level study the urban residency variable has the strongest effect of any census variable on broadband adoption decisions. The estimated odds ratio for broadband adoption in 2006 is between 3.1 and 4.1 for urban residents as opposed to rural residents. This means that the adoption event is much more likely to happen in the urban group than in the rural group. The odds ratio is estimated at between 1.5 and 1.8 for Dublin residents as opposed to non-Dublin residents. The inference is that Dublin residents living in urban areas are more likely to adopt broadband than non-Dublin residents living in rural areas. However, when the analysis is extended to include Internet subscriptions of any kind – and with urban residency included in the model specification - Dublin residency no longer affects the predictive power of the model. These results imply that Dublin residency does not affect the odds ratio for general Internet access. In addition, when the model is extended to include all Internet adoption subscriptions the urban residency variable has a greatly reduced odds ratio of between 1.3 and 1.4. How can we interpret these results?

Broadband access technologies have similar functionalities to the older dial-up technologies. The main difference is higher quality. Although broadband access does provide some additional functionality, for example social media applications, the difference between dial-up and broadband had not become very pronounced by 2006. The results of the household study indicate that the geographic location variables exert largely non-meaningful (i.e. non-substantive) effects on general Internet adoption patterns. Thus, given this finding, and also given the functional similarities of the two services (i.e. dial-up and broadband), I propose that the impacts of the geographic location variables on broadband Internet adoption patterns are not primarily driven by Dublin and urban residents having an inherently greater preference or awareness for broadband access. My alternative explanation for the geographic differences in broadband adoption patterns is that Dublin and urban residents are simply more likely to have the opportunity to acquire broadband in the first place. Thus geographic differences may principally reflect differences in broadband 'availability' rather than differences in broadband 'preference' or 'awareness'. The implication is that Ireland's urban and rural differences in broadband adoption are a function of lack of supply in low density areas. If this analysis is correct, then a lack of broadband availability in low population density areas may have been the key causal factor underlying Ireland's relatively low broadband penetration.

The importance of consumer characteristics

While supply side issues are important, I find that broadband outcomes are also influenced by certain consumer characteristics. For example, the results of the household study indicate that variables signalling greater wealth are associated with improved odds of broadband adoption. Householders from the professional and managerial socio-economic groups have an odds ratio for broadband adoption of between 1.8 and 2.2. The same group has an odds ratio for Internet adoption of between 2.8 and 3.2. Somewhat surprisingly the difference with the rest of the population is therefore more pronounced for general Internet adoption than it is for the more expensive broadband Internet adoption. Similarly, respondents resident in purchaser or owner-occupied accommodation have an odds ratio for broadband adoption of between 1.7 and 2.1, while the same group has an odds ratio for Internet adoption of between 3.4 and 4.2. These two wealth signifying variables are found to have by far the strongest effects of any of the census variables on Internet adoption. Both of these wealth variables exert stronger effects on general Internet adoption than they do on broadband specific adoption.

The effect of income on broadband adoption is less clear. I am unable to establish a statistically significant relationship in the cross country study between the income per capita variable and broadband penetration. The COPSAR dataset used in the household level study does not have an income variable. However, the dataset does contain a job status variable. Job status is likely to be highly indicative of income and is therefore a useful proxy for income. Nevertheless, the model estimates do not show job status to have a strong effect on the odds ratio of broadband adoption. The results of both the cross country level and the household level studies indicate that third level education is positively associated with broadband adoption. However, this effect is not strong and the third level education variable actually diminishes the predictive power of the discrete choice broadband model estimated in chapter six. The cross country results in chapter four suggest that a 10 percentage point increase in the proportion of the 25 to 64 years old age cohort with a third level qualification only increases the broadband penetration rate by between 1.1 and 1.8 percentage points. Ireland exceeds the OECD average in terms of income and education and also had a relatively high level of net wealth during the early years of broadband diffusion. Overall I conclude that the empirical results do not appear to support the argument that the relatively low levels of broadband diffusion in Ireland are attributable to the specific personal characteristics of Irish consumers.

Future prospects

Given that Ireland is already falling behind (see Figure 3.3), and given that Ireland will continue to have commercially unattractive demographics for the foreseeable future (e.g. low population density), should we consider it inevitable that the development of next generation broadband in Ireland will follow the historical trend of relative underdevelopment? On the surface the prospects for the future diffusion of next generation broadband are relatively weak. However, it is possible that, to take Carmen Reinhart and Ken Rogoff's (2009) famous phrase out of context: "this time will be different". The changing nature of telecommunication market structures caused by fast moving technological change offers hope that the development of next generation broadband in Ireland can buck the historical trend of underdevelopment.

Greater inter-platform competition in the future should lead to wider availability and better quality service than in the past. Ireland's telecommunications market has been characterised by monopoly control of the network since the 1890s. There has only rarely been anything approaching real competition in Irish telecommunications markets and for this reason market development and the quality of outcomes has been heavily determined by the investment decisions of the dominant market player, whether it was the publically owned and operated Department of Posts & Telegraphs, or the privately owned and operated Eircom plc. In the absence of competition there is often little rationale for the network owner to invest in network improvements. The generally low levels of investment will have reduced the overall availability and quality of services. However, the future market for high speed broadband in Ireland is likely to be much more competitive than previous markets for telecommunication services. One reason is the expansion of UPC's cable broadband network. A second reason is the expected improvements in the quality of wireless technology. If these improvements materialise then wireless infrastructure may in the future be able to challenge the telephone and cable network operators. Crucially, wireless technology does not have the same extremely high fixed costs that characterise fixed-line technologies and which make Ireland such a commercially unattractive market.

Future broadband policy, including future regulation of the broadband market, should emphasise support for inter-platform competition. However, direct government investment and fiscal support (whether through subsidy or tax break) should only be considered for geographic areas where there is clear evidence of market failure. My results suggest that the probability of future market failure is much higher in rural areas than it is in urban areas. Therefore it may be inappropriate to treat Ireland as a single market for regulatory and other policy purposes. Rather Ireland should be seen as consisting of a number of geographically distinct markets and broadband policy should differentiate between these geographic locations. Any direct financial support to encourage investment should be confined to those locations where the commercial case for high speed broadband service provision is particularly weak and where market failure is judged likely to occur in the absence of direct intervention.

7.4 Where do we go from here?

New and useful knowledge matters for growth and Ireland's ability to harness and exploit knowledge flows will partially determine the country's future economic well-being. Broadband can help Ireland to harness these flows. The overall lack of competition in the past is likely to have stunted telecommunications market development in Ireland. However, monopoly concerns in the Irish broadband market may well recede in the future given Eircom's on-going financial weakness and given increasing levels of investment in the rival cable broadband network. There may be also be future competition in the next generation broadband market from wireless technologies provided there is sufficient improvement in the speed and quality of wireless services. The fast moving nature of advances in communications technology suggests market structures can also change quickly and suggests that regulatory policy should adopt a more flexible stance in the short-term.

It may be a mistake to treat Ireland as a single market for the purposes of broadband policy. Future market failure is far more likely in low population density rural areas than it is in high population density urban areas. This suggests that optimal regulatory and other broadband policies may not be the same for the remote Aran Islands as they are for Dublin city centre. There may be value in slicing the country into different zones for the purposes of broadband policy. A more laissez faire approach may be appropriate in the city centres while a more interventionist approach including direct government support may be more appropriate in rural areas.

Ireland’s demographics such as its low population density appear to present a barrier to the future successful diffusion of next generation broadband. Yet this does not mean that failure is inevitable. Other countries with similarly poor country endowments have achieved far better broadband service indicators than Ireland, and before that, far better telephone service indicators than Ireland. Thus an important area for future research will be more in depth national level case studies of those small European countries that have achieved high broadband efficiency scores, for example Finland, Norway and Iceland. Equally there are likely to be important lessons from studying those small European countries that have achieved poor broadband efficiency scores, for example the Czech Republic and Greece. To avoid policy failure in the future we must consider the lessons of policy successes and failures of the past. Policy must be sufficiently flexible to change if the evidence changes and if the context changes.

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