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Journal of the Association for Information Systems

SPECIAL ISSUE

Is There a Global Digital Divide for Digital Wireless Phone Technologies?[1]

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Abstract

This research examines digital wireless phone adoption among nations and regions that will help to provide a picture of the current global "digital divide." The data are drawn from 43 countries. We present a new theoretical perspective for IS research: a regional contagion theory of technology diffusion. We examine the efficacy of the new theory using empirical regularities analysis, and a vector autoregression and variance decomposition approach to establish information about the strength of the regional contagion links between countries in digital wireless phone diffusion. We found that faster growth of digital wireless phones occurs when a country has: a more well-developed telecommunications infrastructure, more competition in the wireless market, lower wireless network access costs, and fewer wireless technology standards. We also obtained a reading on cross-national influence of wireless diffusion. The countries we studied fell into three regional contagion groups: high, medium and low. The Asia Pacific countries revealed a pattern of homogeneously high regional contagion links, while Western European countries were divided across the three groups. Our findings are supported by a descriptive analysis of diffusion patterns and mini-case assessments.

Keywords: Diffusion, digital divide, digital wireless phones, international issues, public policy, variance decomposition, vector autoregression

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[1] Sanjeev Dewan was the accepting senior editor.

Introduction

Information technology (IT) is an important source of a country's economic growth (Dewan and Kraemer, 2000; Röller and Waverman, 2001). As a result, the gap between those who have access to IT and those who do not—referred to as the "digital divide" (Rice and Katz, 2003)—has received a great deal of attention by researchers and policy analysts (Bridges.org, 2001; Corrocher and Ordanini, 2002; Warschauer, 2004).

International Development Organizations and the Digital Divide

There is a widespread urgency to better understand the digital divide and to reduce the gaps. World leaders from G8 nations, in their 2000 summit meeting, agreed that global digital equality is a prerequisite to achieve and sustain global development (G8 Information Center, 2000). The United Nations Secretary General, Kofi Annan, on World Telecommunications Day, May 17, 2004, told the world: "Today, many people could not imagine daily life without the use of increasingly sophisticated information and communication technologies (ICTs), from television and radio to the mobile telephone and the Internet. Yet for millions of people in the world's poorest countries, there remains a digital divide excluding them from the benefits of ICTs" (United Nations, 2004).

To get a better understanding of the extent of the digital divide, the World Bank; the United Nations Educational, Scientific, and Cultural Organization (UNESCO); and the Canadian International Development Agency funded development of a set of indicators to measure and track the extent of the digital divide across countries over time (Sciadis, 2002 and 2003). One of the key findings is that the extent of the digital divide between developed and developing countries is substantial. Western Europe, North America, Hong Kong, Japan, Singapore, South Korea, Australia, and New Zealand are leaders in IT production and usage, whereas several countries in Africa, and Myanmar and Bangladesh are at the tail end. For example, in 2001, Sweden had consistently high values of info density (an index to measure IT production capability) and info use (an index to measure IT usage) of 228 and 234, while Bangladesh's values were 9 and 11.

The Potential of Wireless Phone Technology

Recently, there have been increasing interests in the potential of digital wireless technology in general, and digital wireless phones in particular, to bridge the divide, thus narrowing social and economic gaps between developed and developing countries (Wireless Internet Institute, 2003).[2] Due to their affordability, popularity, and fast

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[2] Wireless phone technology is different from Internet technology. The Internet uses the TCP/IP open standard to enable seamless global interoperability of its underlying networks (Mendelson, 1999). Thus, standards have never been an issue in the diffusion of the Internet. But there are multiple standards associated with digital wireless phone technology. For example, there are at least five different standards in the second generation (2G) system: CDMA, GSM, TDMA, iDEN, and PDC (Gandal et al., 2003; Koski and Kretschmer, 2005). Also, countries take divergent standardization approaches. Some allow multiple standards to compete. Others require one standard for all operators. This influences diffusion patterns (Farrell and Saloner, 1985; Tassey, 2000). Finally, the competitive landscape of wireless phone operators is different from that of Internet service providers due to the inherent nature of the technology and scale of investment.

infrastructure implementation, digital wireless phones offer several benefits to developing countries whose people and businesses until now have been largely the technology "have-nots." As an alternative to voice communication services, digital wireless phones can substantially improve a country's basic telephone access capabilities in a short period of time (Waverman et al., 2005). Some attractive features of wireless phones, compared with fixed-phone lines, are the shorter (or no) waiting time to gain access, competitive service prices, subsidized handsets, and value-added services.

For example, India has recently experienced a large increase in wireless phone sign-ups due to a price war led by Reliance Infocomm, which reduced the service rate to two cents a minute, the lowest in the world (Kripalani, 2004). Similarly, Nigeria, a country with the third lowest phone penetration in the world, increased its teledensity by more than 350% within months of wireless phone services initiation (Nigerian Communications Commission, 2003). In addition to being substitutes for fixed lines, wireless phones offer substantial economic and social benefits for a country (Waverman et al., 2005). Take India, for example. In 2004, the wireless phone industry contributed to 1% of Indian gross domestic product (GDP), and generated US$3 billion worth of revenues for the government. It also provided substantial gains to businesses in terms of reduction of traveling time, improved logistics, and faster decision making, and finally, played a role in improving the economic and social conditions of rural areas (Lewin and Sweet, 2005).

Research Questions

Despite the significance of digital wireless phones in narrowing the divide, little attention has been devoted to evaluate the extent of the divide and empirically examine determinants of the diffusion of digital wireless phones across countries. Prior research has largely focused on specific countries or regions, such as South Africa (Minges, 1999), Italy and the United Kingdom (Massini, 2004), and the European Union (Gruber, 1999). Meanwhile, other research examines other selected factors that drive wireless growth, such as network effects and pricing (Madden et al., 2004), standards and competition (Koski and Kretschmer, 2005), and the transition from analog to digital technology and competition (Gruber and Verboven, 2001a). Consequently, there is a need for empirical work that jointly examines several factors—some that are unique to wireless phones (e.g., standards) and others that are influential to their adoption and diffusion across a large number of developing and developed countries. Our research attempts to fill this gap. Key research questions that motivate our work are:

- What is the extent of the digital divide for digital wireless phones across countries and regions?
- What factors drive digital wireless phone diffusion, and provide a basis for explaining the digital divide?
- How do these factors vary across economic conditions, especially in developed versus developing countries?

To answer these questions, we developed a model of the determinants of digital wireless phone diffusion suggested from prior literature on the digital divide, international diffusion, and technology spillovers. We will define the digital divide associated with digital wireless phones from two complementary perspectives that help us develop a more refined understanding of the extent of gap across countries. We use data from 43 countries in Africa, Asia Pacific, Middle East, North America, South Asia, and Western Europe to test our model. We applied panel data analysis, vector autoregression, and variance decomposition to capture the influence of within-country and regional factors on diffusion. Our results suggest that high telecommunication infrastructure penetration, competition, and low service prices are likely to increase the rate of growth of digital wireless phone subscribers. But multiple standards slow it down. In addition, the influence of other countries in the same region is an important driver of adoption and diffusion growth of digital wireless phones in a country.

Plan of the Paper

The remainder of the paper is organized as follows. First, we provide a brief overview of digital wireless technology and discuss the background of the development of wireless phone technologies and standards. Next, we review the digital divide literature and identify some gaps. Then, we present our conceptual model and related hypotheses followed by discussion of data, variables in the conceptual model, and preliminary analysis on the extent of digital divide for wireless phones. Next we, present the panel data model, vector autoregression, and contagion link analysis results followed by a brief model-based prediction of future digital wireless phone diffusion. Finally, we conclude with the main contributions and limitations.

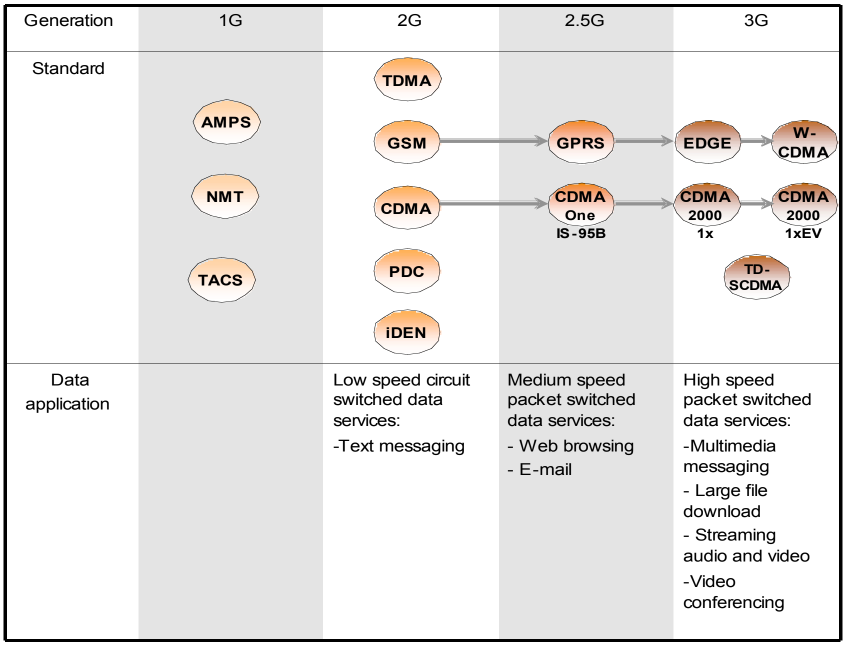
Digital Wireless Phone Technologies

Recently, broadband wireless technologies—technologies that enable wireless high-speed communications—have been recognized as the leading communications technology for the future (Intel, 2004). This family of wireless technologies includes digital wireless phone technology, Wi-Fi, WiMAX, and Ultra-Wideband, each of which is appropriate for different connectivity requirements. Wi-Fi technologies provide high-speed wireless connectivity with a limited range, and are popularly used in places such as homes, offices, cafes, hotels, and airports. WiMAX provides connectivity in a larger geographic area than Wi-Fi; its connectivity typically ranges from one to six miles. UltraWideband is a very high-speed wireless technology, but it has a short range of connection at less than thirty feet (Intel, 2004). Thus, it is likely to be used to interconnect devices (e.g., connection between a printer and PC) in homes and offices. Finally, digital wireless phone technology, particularly third-generation (3G) digital technology, provides coverage across wide geographical areas for mobile devices such as PDAs and wireless phones. Since our research focuses on the digital divide and digital wireless phone technologies, the next section provides background information on wireless phone technologies and the recent statistics on the extent of their worldwide subscribers.

Generational Evolution of Wireless Phone Technologies

Wireless phone networks use cellular technology, which permits a geographical region to be divided into smaller areas called cells within which services are provided. This cell structure allows increased utilization of limited radio frequencies by employing frequency reuse in different cells. The first generation (1G) of wireless phones, introduced in the 1980s, used an analog technology. Some of the widely-used standards are Advanced Mobile Phone Service (AMPS), Nordic Mobile Telephone (NMT), and Total Access Communications System (TACS). Among these standards, AMPS has the largest number of users, mainly in North America. Table 1 presents the evolution of wireless phone technology, standards, and some of their data applications.

Table 1. Evolution: Wireless Phones, Standards and Data Applications



Generation	1G	2G	2.5G	3G
Standard	AMPS NMT TACS	TDMA GSM CDMA PDC iDEN	GPRS CDMA One IS-95B	EDGE → W-CDMA CDMA 2000 1x → CDMA 2000 1xEV TD-SCDMA
Data application		Low speed circuit switched data services: -Text messaging	Medium speed packet switched data services: - Web browsing - E-mail	High speed packet switched data services: -Multimedia messaging - Large file download - Streaming audio and video -Video conferencing

Sources: For additional details on the various analog and digital wireless technology communication standards, the interested reader should see some of the resources that we used. They include: ITU (1999, 2004a), CDMA Development Group (2004), 3G Americas (2005a), and Credit Suisse First Boston (2002).

In the 1990s, digital wireless phone technologies known as the second generation (2G) became available, offering improvements over the existing analog technologies. Digital technologies provide better sound quality and have higher resistance to interference and signal fading. Digital signals require relatively less radio spectrum for conversation too. This increases capacity, making the service capabilities more economical for consumers. And digital technologies provide new value-added services such as data transmission, messaging, and caller alerts. However, since 2G technologies use circuit-switched networks, the data speed remained relatively slow at 9.6 to 14.4 kilobits per second (Kbps). Some of the widely used 2G digital standards are: Time Division Multiple Access (TDMA); Code Division Multiple Access (CDMA); Global System for Mobile Communications (GSM); Personal Digital Cellular (PDC); and Integrated Digital Enhanced Network (iDEN). GSM is the most widely used, including in some 207 countries. Although PDC is used only in Japan, it had the fourth highest number of subscribers in the world after GSM, CDMA, and TDMA in March 2004, according to the GSM Association (2004).

There are several reasons why GSM was successful. GSM was the first large-scale 2G standard introduced in Europe in the early 1990s. This first-mover advantage built strong momentum for GSM in Western Europe, and created a snowball effect in other countries. Today, GSM is the only 2G standard used by operators in several different countries. Also, the European Union required its member countries to use GSM as the sole 2G standard. In our earlier work, we found strong empirical evidence from a sample of nearly 50 countries that one digital wireless phone standard promotes faster technology diffusion (Kauffman and Techatassanasoontorn, 2004 and 2005). Our results suggest that an additional standard reduces the likelihood of increasing subscriber penetration by as much as 98%.

Recently, third-generation (3G) wireless technology has garnered significant attention from businesses, consumers, and the press. In addition to providing improved sound quality, 3G technology enables advanced data and multimedia phone applications, such as e-mail and streaming audio, at very high speeds. 3G is an effort by the ITU to create global standards for wireless communications. The 3G standards are known as International Mobile Telecommunications 2000 (IMT-2000), and they accommodate two sub-standards: wideband CDMA (W-CDMA or Universal Mobile Telecommunications System, UMTS), and CDMA2000.

Another standard, referred to as Time Division Synchronous CDMA (TD-SCDMA), was developed by China in collaboration with Siemens. TD-SCDMA was developed as another alternative for operators worldwide to upgrade to 3G technology. All these 3G standards offer high-speed data services ranging from 2 megabits per second (Mbps) for W-CDMA to 307 Kbps to 3.09 Mbps for CDMA2000. In fact, W-CDMA is a family of 3G technologies that also includes another group of transitional technologies referred to as Enhanced Data Rates for GSM Evolution (EDGE) technologies. Similarly, CDMA2000 includes CDMA2000 1x and CDMA2000 1xEV. 1x has lower voice capacity and slower data speed than 1xEV.

However, since it takes years to upgrade existing networks, several operators have opted for phased migration through a set of transitional technologies. These are known as 2.5G technologies, and they allow wireless devices to use packet-switched networks for faster data downloads. General Packet Radio Service (GPRS) and CDMAOne (IS-95B) are the 2.5G technologies for GSM and CDMA standards. Data speeds for GPRS and CDMAOne are 115 and 64 Kbps.

Deployment and Subscriber Penetration

The first 3G network using CDMA2000 technology was deployed in Korea in 2000. Since then, operators in Western European and Asian countries, such as Hong Kong and Japan, have provided services on their 3G networks using either the W-CDMA or CDMA2000 technologies. W-CDMA, with a large installed base of GSM networks, has demonstrated advantages over the CDMA2000 standard to become a market leader. Due to technology lock-in, GSM operators probably will upgrade to W-CDMA, rather than making their prior investments in the GSM standard irrelevant. However, it is too early to predict what will become the dominant standard.

Figure 1 shows a breakdown of worldwide subscribers of wireless phones as of March 2004, with data from the GSM Association (2004).

There were 1,456.5 million wireless phone subscribers worldwide, with 16.5 million (1%) and 1,440 million (99%) as analog and digital subscribers, respectively. Among the digital standards, GSM had the largest subscriber base with 1,046.8 million subscribers (71.9%), followed by 199.1 million CDMA subscribers (13.7%), and 111.2 million US-TDMA subscribers (7.6%).

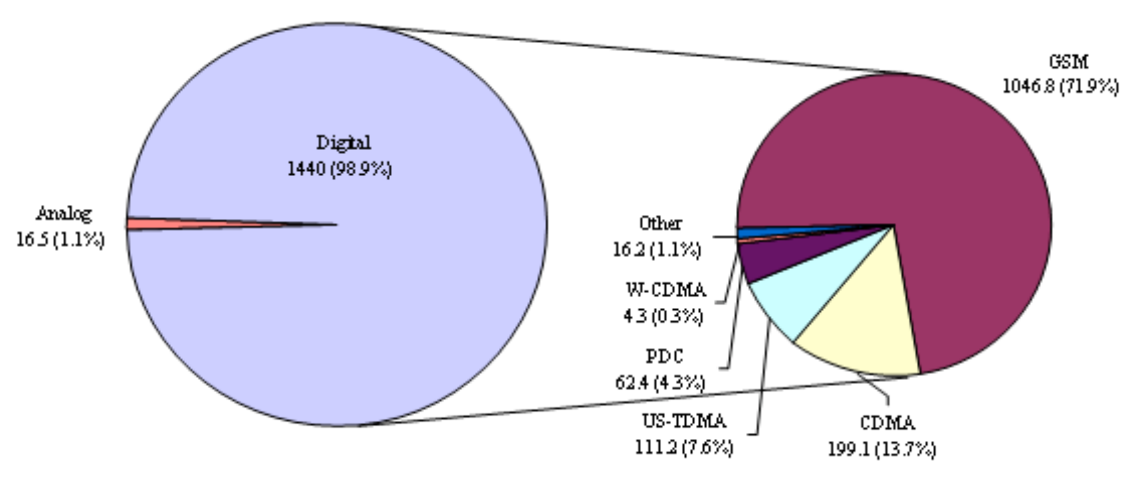


Figure 1. Worldwide Wireless Phone Subscribers (Millions), March 2004

Source: GSM Association Web site (www.gsmworld.com)

Literature Review

We review research that examines digital divide issues across various technologies to summarize the major findings, to identify key variables that these studies use, and to indicate some gaps in the literature to position our contributions. The prior research guides our choices of factors that may explain digital wireless phone diffusion at the country level.

Digital divide research has addressed a number of questions to help us better understand the complexity surrounding the issues. Two key questions have come to dominate much of the past research: (1) How should the digital divide be defined and measured? (2) What are the determinants of technology adoption and diffusion that can help explain the digital divide?

Digital Divide: Definitions and Measures

Several researchers (Bertot, 2003; Dimaggio and Hargittai, 2001; Warschauer, 2004) suggest that the typical definition of digital divide that is commonly used in the popular press and academic literature—which points to IT access gaps—is too narrow. They argue that this definition is often misleading relative to the various ways that policy makers attempt to put into place the means to narrow the digital gaps. As a result, there is some recognition that broader definitions and approaches that may be used to look into these issues from a number of different perspectives might be more appropriate to extend our understanding beyond the idea of an access gap.

Bertot (2003), for example, argues that the digital divide, with an emphasis on the Internet, should be considered along several dimensions, including the breadth and quality of access to technology, the availability of effective telecommunication infrastructures, the presence of parallel economic development, and information access and information literacy. Similarly, Dimaggio and Hargittai (2001) suggest that research should move on from the dichotomous measure of the digital divide as “haves” and “have-nots” to study differences among people with access to the Internet. They call this digital inequality. Digital inequality, in turn, encompasses five dimensions: technical means (hardware, software, and connectivity), autonomy (location of access, freedom to use), use patterns (purposes of the Internet uses), skills (ability to use the Internet effectively), and social support networks (access to advice from more experienced users).

Hargittai (2002) uses this framework to examine Internet usage and finds empirical support for the influence of skills in Internet searches. This is reflected in the various ways that people find content online and the large variance in the amount of time they take to accomplish their searches. In his book, Warschauer (2004) draws upon his field observations of projects that were aimed at improving people’s lives through IT in a number of countries. He focuses the attention on the embedded and social nature of technology access with respect to an array of other factors, including physical, digital, human, and social resources. He argues that content and language, literacy and education, as well as community and institutional structures must seriously be considered relative to the existence of a variety of digital divides.

Another ongoing stream of research seeks to explain the existing digital divides by developing concrete measurements and identifying determinants of technology adoption. To address the criticisms on the limited view of the digital divide in the literature, several studies have attempted to develop new measures that incorporate other aspects beyond the accessibility of a technology. Corrocher and Ordanini (2002) develop aggregated measures of digital divide across IT and apply them to evaluate the extent of digitization among eight Western European countries, Japan, and the United States. Their aggregate measure considers factors that explain the intensity and speed of adoption, including markets, diffusion, infrastructures, human resources, competitiveness, and the degree of competition. The results illustrate that the United States is a clear leader in the new digital economy environment. Its digitization index leads others by a large margin. The United Kingdom, Japan, and Germany are somewhere in the middle, while France, Spain, and Italy seem to have fallen behind in this new world.

In a large-scale project funded by the World Bank and UNESCO, Sciadis (2003) proposes three new indicators to measure the divides. Info-density measures a country’s productive capacity through connectivity, skills, and education. Info-use measures a country’s consumption of IT through the extent of the penetration of IT and usage. Info-state, finally, is an aggregated index of info-use and info-density. Sciadis then applies three indicators to reveal the magnitude and evolution of the digital divide in more than 130 countries over the 1996 to 2001 period. The main findings point out that there is a large digital divide between developed and developing economies. The author also finds that both info-density and info-use contribute to the digital divide, particularly through different degrees of connectivity and penetration. He also reports that there are increases in info-state across all countries during the study period. The author interprets this to mean that the digital divide is closing, although this seems to be occurring at a slow pace.

Alternate Explanations for Why the Digital Divide Exists

Others have been exploring how to explain why the digital divide exists by examining factors that influence technology adoption and diffusion. Corrocher and Ordanini (2002) show that the speed of technology diffusion is associated with several factors. Some are economic in nature (e.g., GDP per capita, income distribution, access cost), while others involve human capital (e.g., the level of education of the population, skills), infrastructure (e.g., telephone density), and government policies and actions. The link between economic development, particularly GDP per capita, and access to IT has been well supported in the literature. Some examples include Beilock and Dimirova (2003), Caselli and Coleman (2001), Hargittai (1999), Hawkins and Hawkins (2003), Huang et al. (2003), Kiiski and Pohjola (2002), and Quibria et al. (2003).

The final paper by Quibria and his colleagues examines the determinants of the digital divide in more than 100 countries. The authors show that income level in a country is a determining factor for national level adoption and diffusion of older technologies. Those include fixed-line telephones, fax machines, and televisions and newer technologies such as PCs, the Internet and wireless phones. In the case of the Internet, there is increasing empirical evidence to demonstrate that telecommunication infrastructure, such as telephone density and the extent of computer penetration, is associated with growth (Beilock and Dimirova, 2003; Huang et al., 2003; Hawkins and Hawkins, 2003).

The results reported on the role of education on technology growth are mixed. That is, education is not always an important determinant across the diffusion of all technologies. Nevertheless, it appears that education is important in the diffusion of computers and the Internet (Caselli and Coleman, 2001; Kiiski and Pohjola, 2002; Quibria et al., 2003; Robison and Crenshaw, 2002) where users need to possess certain skills in order to use them. This does not appear to be the case for wireless phones, though (Quibria et al., 2003). This important finding adds to yet more evidence of the potential of wireless phones to be widely adopted across populations, thus narrowing the digital divide in the countries where wireless diffusion occurs.

Robison and Crenshaw (2002) test the interaction between education and some other variables. They find that education, measured as secondary school enrollment ratios, conditions the magnitude of impacts of development, political openness, and the tertiary labor force on the diffusion of the Internet. Consequently, governments, particularly those in developing nations, should emphasize human capital in their national strategies to promote the Internet.

Hargittai (1999) and Huang et al. (2003) offer contrasting views. They do not find as much support for the influence of education on the growth of the Internet. There is a plausible explanation why this may be the case. These two studies, compared with others that explore at least 90 developed and developing economies, have a relatively smaller number of countries in their samples. Hargittai (1999) reports on 18 OECD countries. Huang et al. (2003) reports on 28 mostly developed countries in North America, Western Europe, and Asia. It is possible that the small sample sizes, along with the small amount of variance in the values of the education variable, prevent education from being a significant predictor of Internet development. In fact, Kiiski and Pohjola (2002) perform a sub-sample analysis and find that education becomes significant only in a large sample of developed and developing nations. They also report that it is insignificant when just OECD countries are tested.

Some other studies, depending on the countries that are tested and the specific policies that are examined, affirm the role of telecommunication policy as a driver of technology growth. For example, Hargittai (1999) and Hawkins and Hawkins (2003) find that policies related to the degree of competition in the telecommunications sector and policies related to the reduction of connection and usage fees are among the predictors of a country's Internet connectivity. Evidence from case studies (Hawkins, 2005; Tipton, 2002) attests to the significance of the role, policies, and actions of the government to promote technology adoption and address the digital divide in several developing nations.

A Synthesis: Gaps in the Digital Divide Literature

Although the previously discussed research significantly improves our understanding of the nature of the digital divide for some technologies at the country level, we still identify gaps in the literature. First, despite calls from several researchers to recognize the broader definition of the digital divide beyond the "haves" and "have-nots" dichotomy, much of the existing research examines the issue through the simplistic perspective of technology access. Although this is helpful for a first-cut understanding of the digital divide associated with a particular technology, we also need studies that can provide deeper understanding. We believe that this will occur through the application of multi-dimensional definitions of the digital divide.

Second, despite the increasing interest in wireless technologies, particularly digital wireless phones, to potentially solve or at least narrow the digital divide between developed and developing countries (Wireless Internet Institute, 2003), there is a lack of empirical study examining the diffusion of these technologies across a set of developed and developing countries to evaluate the existence and the extent of the digital divide and identify important determinants of their diffusion. Most of the prior empirical work examines the diffusion in one or a few countries (Botelho and Pinto, 2004; Iimi, 2005; Massini, 2004). As a result, there is a need for theory-based empirical studies to improve our understanding of the global digital divide of wireless technologies.

Third, despite the fact that the diffusion of new communications technology (particularly the Internet and, more recently, wireless technologies) is a global phenomenon, most of the existing studies discussed in the previous review have focused on within-country determinants of diffusion. However, international diffusion research in Marketing (e.g., Putsis, et al., 1997) and the spillovers literature in Economics (e.g., Grossman and Elhanan, 1991; Keller, 2002) recognize that the increasing interconnectedness and information flow between individuals, businesses, and countries is likely to lead to cross-country influences on the global diffusion of a new technology. Since the cross-border influence is missing in the literature, our understanding of the global diffusion of a new technology is still not complete.

Conceptual Model and Hypotheses

We next discuss foundational elements of a conceptual model for this research, and its theoretical predictions, stated as hypotheses about the role of within-country drivers and geographical influences on wireless phone diffusion.

Conceptual Model

We combine two perspectives—the digital divide literature that provides within-country variables, and the international diffusion and spillovers literatures that suggest geographical influences—to develop an integrative model to assess global diffusion of digital wireless phones (Figure 2).

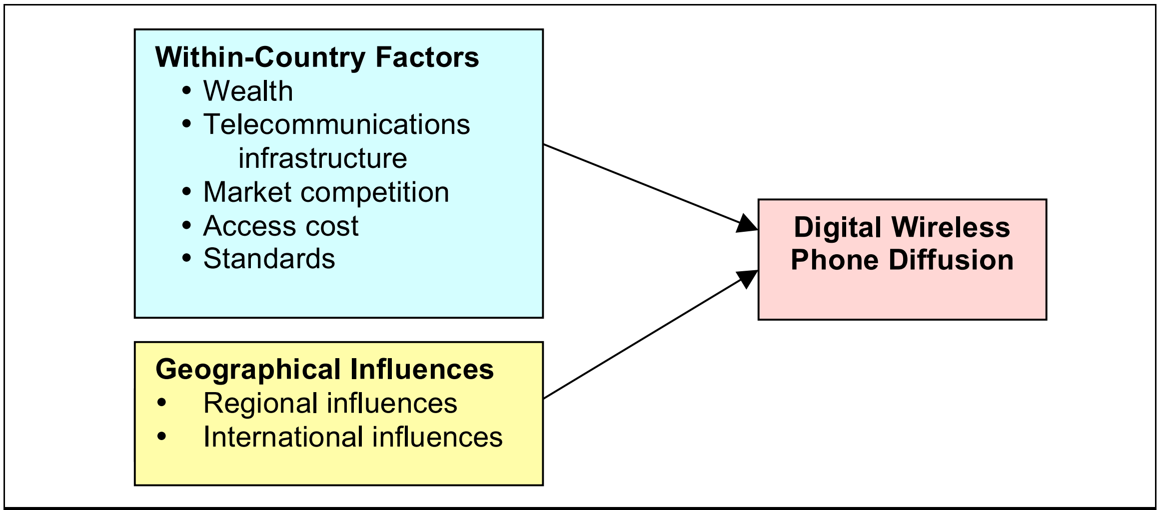


Figure 2. A Model of the Determinants of Digital Wireless Phone Diffusion

Our model focuses on understanding the global divide of digital wireless phones by examining important drivers of their diffusion. Thus, we specify the extent of digital wireless phone diffusion within a country as the dependent variable in the conceptual model.

Economic, social, and policy factors are among the wide range of within-country factors that we found from a review of previous studies of the digital divide. The present study focuses on the most commonly evaluated determinants in previous literature: economic wealth and telecommunication infrastructure.[3] We also add two related variables drawn from the economic theory, market competition and costs of access to technology, which may affect adoption decisions. For example, the demand for a technology depends on its price (Parker and Röller, 1997) and the level of market competition among digital wireless phone operators (Fullerton, 1998; Gruber, 1999). Depending on their values, both price and market competition may stimulate the launch of new and attractive services to engender widespread market adoption that is likely to drive down prices, which further encourages adoption (Koski and Kretschmer, 2005). Another potential driver of adoption, technology standards, is particularly relevant in the context of wireless phones. As discussed earlier, some countries (e.g., France, Germany, United Kingdom) widely support one standard, while others (e.g., India, the U.S., Indonesia) have multiple

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[3] Wireless phones face capacity constraints that affect competition. In contrast, the capacity of the Internet is almost unlimited. It is only constrained by the capabilities of the communication lines. Wireless phone systems use radio frequencies, scarcer resources. Wireless phone operators bear the burden of large-scale investments in infrastructure. Also, costly license fees further impact their ability to compete. To effectively manage limited radio frequencies, governments around the world tend to offer few wireless phone licenses. For example, Hong Kong, which is considered as one of the most competitive telecommunication markets in the world, had more than 200 Internet service providers but only six wireless phone operators in 2004 (Ingelbrecht and Trivedi, 2004; Trivedi, 2004).

standards in use. From the public policy perspective, this is an important question whether to support early standardization by enforcing operators to use one standard or to leave it to market mechanisms to decide the dominant standard.

Other than within-country factors, the international marketing and spillovers literatures suggest that cross-country influences can be another source of important drivers of global technology diffusion. This is because the global environment is characterized by increased access to information (e.g., the Internet), growing cooperation among firms (e.g., outsourcing), and blurring national borders (e.g., due to the North American Free Trade Agreement, NAFTA). Further, even though the new communications technologies and the Internet enable the connectivity of individuals and businesses in many locations, the empirical literature shows that the benefits of knowledge spillovers decline with distance (Keller, 2002). This suggests that a country's technology diffusion is more likely to be influenced by near neighbors than by those at a distance. This finding makes sense because neighboring countries or countries located in the same geographical region are more likely to share similar economic conditions, political ideologies, cultural traits, and even spoken languages (Hawkins et al., 1981). This, in turn, makes it more likely that their people will share information. This leads us to believe that, other than within-country factors, a country's diffusion is also influenced by the diffusion process in other countries within the same region.

We next develop hypotheses that relate these determinants to the diffusion of digital wireless phones.

Hypotheses Related to Within-Country Factors

Our hypotheses explore the impact of within-country factors and geographical influences on the global diffusion of digital wireless phones, and are based on the foregoing material and the theoretical arguments to follow.

Among the country-specific factors, five constructs are likely to play an important role in the diffusion of digital wireless phones: wealth, telecommunication infrastructure, market competition, access cost, and standards. (A critical issue, as the reader will see later, is whether each of these constructs can be measured in a manner that ensures orthogonality of the underlying information associated with them.)

Wealth. Several studies in the digital divide and diffusion literatures have found that economic wealth predicts a population's adoption of new technologies (Gatignon and Robertson, 1985; Hargittai, 1999; Kraemer et al., 2002; Tellis et al., 2003). From the technology providers' perspective, a country's economic strength will affect technology diffusion: the necessary resources are more likely to be present, and capital required for the expansion of the technology is more obtainable in richer countries (Hargittai, 1999). More generally, it is likely that greater technology infrastructure will be observed in wealthier countries, although the literature offers us no guidance as to the extent of their co-occurrence. In the case of digital wireless phones, based on public statements by a number of operators, upgrading from GSM/GPRS to EDGE networks, for example, costs about US$1 to US$2 million dollars to cover one million existing and potential customers in a service area (3G Americas, 2005b). Such expansion of the capacity and coverage of networks will enable operators to offer innovative services (e.g., multimedia messaging, audio and video streaming) at relatively lower costs, which, in turn, increase the attractiveness of the technology and simultaneously enlarge the pool of potential adopters, thus increasing the likelihood of adoption.

Another general finding in diffusion research is that early adopters are wealthier than later adopters (Rogers, 2003). This is because wealthy people, with their higher disposable income—and thus wealthier countries in the aggregate—can afford to take on the risk of adopting a new technology earlier at higher prices (Tellis et al., 2003). With the supporting evidence of the importance of wealth related diffusion, we propose the following hypothesis:

- **Hypothesis 1 (The Wealth Hypothesis)**: Countries with greater economic wealth are likely to experience more rapid digital wireless phone diffusion.

Telecommunication Infrastructure. The diffusion and digital divide literatures suggest that telecommunication infrastructure explains gaps associated with the digital divide and influences technology diffusion across countries (Hargittai, 1999; Huang et al., 2003; Kraemer et al., 2002; Quibria et al., 2003). In a broader digital divide context, telecommunication infrastructure is viewed as a fundamental means for people and businesses to participate in the digital economy. Also, network infrastructure (such as telephone lines per capita, Internet connectivity, and wireless phones per capita) is an important component (in addition to skills related to ICTs) of info state—a country's productive capacity relative to technology. This is one of the indices used to evaluate the magnitude and evolution of the digital divide (Sciadis, 2003). More importantly, closer examination of these indices across more than 190 countries reveals that the extent of network connectivity, particularly from newer technologies such as the Internet and wireless phones, contributes to the size of the digital divide across those economies.

Looking specifically at diffusion of a particular technology, certain infrastructures provide necessary resources for the use of the technology. To use the Internet, for example, one needs a personal computer (PC), or another device, and a connection, including a phone line or broadband connection. As a result, several studies use PC penetration and availability of telephone lines as measures of infrastructure and find explanatory power for the variation in Internet development across different countries (Beilock and Dimitrova, 2003; Hargittai, 1999; Huang et al., 2003).

Basic telecommunication infrastructure is relevant to digital wireless phone diffusion because it may constrain or facilitate wireless implementation and usage, due to tensions with cross-product substitution. On the one hand, the extensive availability of basic infrastructure (especially phone lines) may slow down the diffusion of wireless phones, which are considered to be a substitute for voice communication (Talukdar et al., 2002). On the other hand, the high availability of telephone lines is associated with more Internet connectivity. So, digital wireless phones, with the mobility that they offer, provide a better alternative, compared to PCs, for consumers to access information on the Internet. Because our research focuses on digital wireless phones that have the capabilities beyond analog wireless phones to use data services, we expect that countries with a large number of telephone lines per capita will experience faster diffusion. This leads to the following hypothesis:

- **Hypothesis 2 (The Infrastructure Hypothesis)**: Countries with a greater telecommunication infrastructure penetration are likely to experience more rapid digital wireless phone diffusion.

Market Competition. The importance of market competition on technology diffusion has been well documented in the literature. The diffusion is faster when there is a high level of competitive activity (Gatignon and Robertson, 1985). Competition generally influences technology diffusion via two mechanisms: non-pricing strategies and pricing strategies that technology providers carry out (Corrocher and Ordanini, 2002; Hargittai, 1999; Koski and Kretschmer, 2005; Parker and Röller, 1997).

One of the common non-pricing strategies that wireless phone operators use is product differentiation. In some cases, the differences are embedded in the services they offer, including network coverage and capacity, and quality of service (Choi et al., 2001; Fullerton, 1998). In other cases, phone operators offer special services and enhancements, such as call forwarding, voice mail, call waiting, and special billing service. They expect this will enable them to secure additional subscribers or charge higher prices (Fullerton, 1998). Aggressive pricing strategies resulting in lower prices are typically observed in a competitive market (Fullerton, 1998; Koski and Kretschmer, 2005). The empirical evidence suggests that such price reduction is likely to influence demand, increasing diffusion (Gruber and Verboven, 2001a; Parker and Röller, 1997). Thus, we propose the following hypothesis:

- **Hypothesis 3 (The Market Competition Hypothesis).** Countries with higher market competition are likely to experience more rapid digital wireless phone diffusion.

Access Cost. The access cost places a barrier on technology adoption decisions (Rogers, 2003). The costs associated with digital wireless phone services are similar to those of Internet services. That is, a user pays a fixed cost to acquire the necessary hardware and a one-time subscription fee. In addition to the fixed cost, a user has to pay a variable cost of monthly usage fee—in flat or metered rate terms—to a service provider.

Prior research that has studied the link between the cost of Internet access and its diffusion in several countries (e.g., China, Chile, India, South Korea) found that lower computer costs combined with lower access costs make the Internet more affordable and facilitate its growth (Hawkins, 2005; Lee et al., 2003; Press et al., 2002). Additionally, the most recent large-scale survey of 57,000 households in 2003 by the United States Department of Commerce reported that one of the reasons that households have no Internet connection is its costs. About 23% of the surveyed households cited that it is too expensive to get a connection (United States Department of Commerce, 2004). Based on the evidence in the literature, we hypothesize that there is a link between digital wireless phone access costs and its diffusion as follows:

- **Hypothesis 4 (The Access Cost Hypothesis).** Countries with lower digital wireless phone access costs are likely to experience more rapid digital wireless phone diffusion.

Standards. The economic literature defines a standard as a set of technical specifications that a producer complies with tacitly, or formally agrees to, or conforms to via an explicit regulatory authority (David and Greenstein, 1990). Among the different kinds of standards discussed in the literature (Antonelli, 1994; David and Steinmueller, 1994), compatibility standards are the most important to IT, particularly for new technologies that are subject to network effects (Farrell and Klemperer, 2005). The economics of standardization—especially compatibility across technology platforms—and its implications for innovation, diffusion, market, and social welfare have largely been explored in the literature (e.g., Gandal et al., 2003). In particular, the debate centers around the advantages and disadvantages of market-based (multiple or competing) standards and mandated (single) standards (Farrell and Saloner, 1985). Such debate is relevant to the digital wireless phone industry because some countries chose a market-based approach, while others chose a mandated standard. In 2G digital wireless phone services, the U.S. let the market decide which standard would become the leader by allowing phone operators to freely choose from four standards. The standards included CDMA, GSM, TDMA, and iDEN (Gandal et al., 2003; Koski and Kretschmer, 2005). The European Union, in contrast, mandated a single standard, GSM, with which all operators had to conform (Gruber and Verboven, 2001b).

The theoretical literature suggests that a single standard offers several benefits to both consumers and producers (Farrell and Saloner, 1985; Gandal et al., 2003; Gruber and Verboven, 2001b; Koski and Kretschmer, 2005; Tassey, 2000). First, relative to competing standards, a single standard reduces confusion and uncertainty among consumers and tends to help them realize the benefits from direct network externalities faster. As a result, consumers can reap more value by connecting to others in a compatible network. Second, due to the benefits of indirect network externalities, complementary goods and services (e.g., applications, accessories) are cheaper and more widely available at perhaps lower prices. Third, adopting a single standard provides larger scale economies in handset and network infrastructure equipment production. All these benefits seem to suggest that a country that mandates a unified, single standard may experience faster diffusion. However, there also are some downsides of a single standard. These include limited choices for consumers and the possibility of lock-in to an inferior standard.

Competing standards provide at least two benefits (Gandal et al., 2003; Gruber and Verboven, 2001b). First, services are likely to differ across standards in ways that may be beneficial in terms of social welfare. For example, CDMA systems provide more and even better data services than GSM systems (Gandal et al., 2003). Second, multiple standards motivate competition. This is likely to lead to lower prices and better technology in the long run, thus reducing the risk of lock-in to an inferior technology. Similar to a single standard, these benefits also lead us to believe that faster diffusion is likely in a country that chooses to implement a multiple standard scheme. Some of the disadvantages of competing standards—which are the advantages of the single standard—are the lack of scale economies, and the limited benefits of network externalities.

In summary, the theoretical literature is not conclusive in terms of which standardization approach yields superior social welfare. However, the limited empirical evidence from Gruber and Verboven (2001b) and Koski and Kretschmer (2005) suggests that standards competition slows down the diffusion of analog and 2G digital systems. Koski and Kretschmer's results were limited to 32 industrialized countries, but they are useful and representative. Based on the supporting arguments we have made and the available evidence in the literature, we propose the following hypothesis on the role of standards on diffusion:

- **Hypothesis 5 (The Standards Hypothesis)**: Countries with a single standard are likely to experience more rapid digital wireless phone diffusion.

Hypotheses Related to Geographical Influences

Much of the past diffusion research (e.g., Beilock and Dimirova, 2003; Hargittai, 1999; Huang et al., 2003) examines the link between within-country variables and technology diffusion. As a result, little is known about if and to what extent technology adoption in one country affects adoption and diffusion growth in other countries (Putsis et al., 1997). Recent results suggest that cross-country interaction is an important variable to explain diffusion of a new innovation in an increasingly global environment. Putsis et al. (1997) investigated the influence of cross-country interaction variables measured by external contacts with other countries on the diffusion of four products (VCRs, microwave ovens, compact disc players, and home computers) in ten European Union nations. The authors found that the pattern and strength of cross-country interaction are important considerations in the diffusion of these products.

Tellis et al. (2003) provide three additional reasons, in addition to cross-country contacts, for why innovation growth in some countries may affect diffusion growth in another country. For clarity in our discussion, let’s call this country “Country 1.” First, the intense media coverage about the success and fast growth of an innovation in other countries is likely to increase the attractiveness of such innovation to entrepreneurs in Country 1, and trigger investment and business activity around it, also causing adoption and diffusion to occur there. Second, the success of an innovation in other countries also is likely to prompt manufacturers and service providers to promote sales in Country 1, which subsequently may lead to further diffusion growth there. Third, the fast growth of a technological innovation in other countries is likely to create a good impression about such innovation. This will further increase its acceptance and lead to broader adoption in Country 1. Thus, there is compelling evidence from these empirical findings that leads us to believe that our understanding of the global diffusion of digital wireless phones will not be complete if we ignore the impacts of cross-country influences.

However, it is clear that the diffusion literature in marketing discussed earlier offers an explanation of cross-country influences that is based on interactions between individuals across countries and the extent of media coverage. The spillovers literature in economics adds two other channels of the cross-country influence: international trade and foreign direct investment (Keller, 2004). These two economic activities are likely to enable knowledge spillovers: learning about innovations, their uses by firms, and operational characteristics in firms in advanced countries (Caselli and Coleman, 2001). In addition, there is also strong empirical evidence that spillovers tend to be geographically localized: the benefits from spillovers decline with the geographic distance between countries (Keller, 2002).

Based on the theoretical support and empirical findings from the marketing and economics literature, we expect to find that regional influences are present in the global diffusion of digital wireless phones. More specifically, we expect that countries within the same geographical region will influence each other in the adoption and diffusion of digital wireless phones. Thus, we propose the following hypothesis:

- **Hypothesis 6 (The Regional Influences Hypothesis)**: Countries within the same geographical region are likely to be influenced by other countries in the diffusion process for digital wireless phones.

Previous research suggests that developed and developing countries are fairly different in their levels of IT usage (Dewan and Kraemer, 2000). Research that examines diffusion of specific technology (e.g., computers, the Internet) also reports similar findings (Caselli and Coleman, 2001; Huang et al., 2003). That is, some regions (e.g., Africa) and developing countries have been experiencing slower technology diffusion. Empirical evidence relates such slow diffusion and low IT usage to the lack of complementary resources (e.g., infrastructure, human capital, and information-oriented business processes) to leverage the business value of IT (Dewan and Kraemer, 2000; Zhu and Kraemer, 2005). Motivated by the previous findings, we will test the following hypothesis:

- **Hypothesis 7 (The International Influences Hypothesis)**: The strength of within-country factors differs between developed and developing countries.

Data, and Pre-Empirical Analysis

We next discuss our data collection and measurements of variables in the conceptual model that permit us to test the theory embodied in our hypotheses. We also provide a high-level pre-empirical analysis of the data to identify quantitative evidence for the digital divide in wireless phones. Finally, we assess data that provides an indication of differences in diffusion of 2G, 2.5G, and 3G digital wireless technologies.

Data Sources and Collection

We use annual data that cover 43 countries in Africa, Asia Pacific, Middle East, North America, South Asia and Western Europe. Most countries did not introduce digital wireless phones in the same year. For example, several Western European countries, such as Denmark, Finland, France, and Germany adopted early in 1992. Others followed some years later, such as Malaysia in 1995, Saudi Arabia in 1996, and Egypt in 1997. As a result, the number of data points varies from country to country, but all observations in this part of our analysis end in 2002 for most countries. This is due to the availability of data from the major international data sources. The latest annual data was available, with the exception of Iceland, Italy, New Zealand, Sweden, and Vietnam, where data are available up to 2001 only. Our key sources of data are the publications of the ITU, the Gartner Group, the GSM Association and the CDMA Development Group Web sites, the Euromonitor, and various wireless phone operator Web sites. To maintain the accuracy and reliability of the data, we validated the value of our variables by cross-checking them with different sources that cited the same facts.

Limitations of the data prevent us from having some regions (e.g., Latin America) and all countries in each region included.[4] We have selected countries that are the most

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[4] The three African countries are Egypt, Morocco, and S. Africa. Twelve Asia Pacific countries are Australia, China, Hong Kong, Indonesia, Japan, Korea, Malaysia, New Zealand, Philippines, Singapore, Thailand, and Vietnam. There are two S. Asian countries: India, and Pakistan. The six Middle East countries are Iran, Jordan, Kuwait, S. Arabia, Turkey, and UAE. Two North American countries, U.S. and Canada, are represented. Eighteen European countries are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland, and the United Kingdom.

representative from each region. As a result, there are other countries from specific regions that are not in our sample that still ought to share similar digital wireless phone subscription patterns with countries that are in our sample. This way, the results of our analysis can be generalized to countries outside our sample.

Operationalization of Variable Measures

We next discuss our operationalized measures of the definitions that we gave earlier for the digital divide and explain the measures of the dependent and independent variables in our conceptual model. Recall that the popular definition of the digital divide that is commonly used in the literature is the gap between those who have access to IT and those who do not. Prior research operationalizes this gap by using measures of Internet technology penetration, such as number of Internet hosts per 10,000 people (Hargittai, 1999) or number of Internet users per 1,000 people (Beilock and Dimirova, 2003). To be consistent with the literature, our first dimension of the digital divide in digital wireless phones is subscriber penetration gap, the difference in digital wireless phone subscriber penetration between countries.

Several researchers (Bertot, 2003; Warschauer, 2004) argue that although a one-dimensional definition is helpful to get an initial understanding of the digital divide associated with technology access, it is not sufficient to understand some of the other complexities of the digital divide. To address these concerns, some researchers (Dimaggio and Hargittai, 2001; Davison and Cotten, 2003) propose other dimensions that explain why the digital divide arises among those who have access to the technology. The inequalities in hardware, software, and connections, among other factors, are viewed as being crucial. They represent differences in Internet experience that are likely to lead to differences in perceived value and user satisfaction from the technology (Dimaggio and Hargittai, 2001). For example, Davison and Cotten (2003) analyzed the Internet usage behaviors of more than 1,000 users and found that broadband users are likely to spend more time on the Internet than are dial-up users. Their results suggest that the larger bandwidth of broadband connections enables users to do more things online (e.g., using applications with more sophisticated graphics, and streaming audio and video) in less time.

The different generations of digital wireless phones (2G, 2.5G, and 3G) are similar to the different types of connections that users have experienced over the years with the Internet. The slowest connection is 2G, the fastest is 3G, and 2.5G is somewhere in the middle. Following the argument about dial-up versus broadband Internet connections, we expect that these differences will likely limit the perceived value for 2G and 2.5G subscribers compared to 3G subscribers, who can be expected to reap greater benefits. Based on this argument, we define a second dimension of the digital divide in digital wireless phone usage as the generational penetration gap. This is the difference between the extent of 2G, 2.5G, and 3G penetrations across countries.

Two variables related to our definitions of the digital divide discussed above are the number of digital wireless phone subscribers and the extent of 2G, 2.5G and 3G penetrations. We use the percentage of digital wireless phone subscribers in a country's population to measure the extent of subscription. Similarly, we expect to use the percentage of 2G, 2.5G, and 3G subscribers to measure the extent of their penetration in a country. However, we do not have access to that kind of data. Instead, we will use a proxy variable, the percentage of 2G, 2.5G, and 3G handsets sold in a country, to measure the extent of their penetration.

In our conceptual model, we use percentage of digital wireless phone subscribers as a measure of the dependent variable, the extent of digital wireless phone diffusion. Five within-country factors are: wealth, telecommunication infrastructure, market competition, access cost, and standards. We use purchasing power parity adjusted GDP per capita (GDP) to measure economic wealth. We use the number of fixed-phone lines per 1,000 people (PHONE) to measure telecommunication infrastructure. Market competition is measured by the number of digital wireless phone operators (COMP). Although the total access costs include the cost of a handset, a one-time subscription fee, and a monthly usage cost, prior research points out that the price of handsets has steadily declined over the past several years (Valletti and Cave, 1998). Also, operators worldwide regularly offer subsidies, including a handset or a free phone, as a means to create a market (Kim et al., 2004). In turn, operators recoup those subsidy losses by charging higher usage fees (Valletti and Cave, 1998). In fact, the evidence suggests that monthly usage costs are perhaps the biggest cost burden that factors into a decision to adopt wireless phones. As a result, we measure access costs based on fees for the use of digital wireless phone services as purchasing power parity-adjusted fee for a three-minute peak-rate local call (COST). The last variable, standards, is measured by the number of digital wireless phone standards (STD) used in a country. Finally, there is no direct measurement for regional influences. Instead, we will use the results from our empirical analysis, which we will discuss later in this section, and combine them with other modeling techniques to capture their effects. We display summary statistics for the key variables in Table 2.

Table 2. Summary Statistics of Key Variables in the Conceptual Model

Variable	Measure	Mean	Std. Dev.
Dependent variable			
Extent of diffusion	Subscriber penetration percentage	22%	27%
Independent variables			
Wealth	PPP-adjusted GDP per capita (in constant international dollars)	17226	10215
Telecomm infrastructure	Fixed-phone lines per 1,000 people	382	231
Market competition	Number of operators	3	1.4
Access cost	PPP-adjusted fee, three-minute peak-rate local call (in constant international dollars)	48	150
Standards	Number of standards	1.3	0.7

Pre-Empirical Analysis I: Digital Divide—Subscriber Penetration Gaps

Before we discuss our analysis of the digital divide, it is important to point out that our analyses in this section and in the next section on the panel data model align data for all countries by diffusion years, not calendar years. Aligning data by calendar years would permit us to test time-specific factors that impact all countries, for example, the slowdown of the world economy, or a shortage of handsets worldwide. However, diffusion years are more appropriate in our research setting, because they enable us to compare the multiple trajectories of diffusion in different countries and test the influence of factors at the same diffusion stage.

We examine two dimensions of the digital divide: (1) subscriber penetration gaps to determine the access gap to the technology and (2) generational penetration gaps to assess inequality of usage and value derived from digital wireless phone technologies. Table 3 displays subscriber penetration among 43 countries, grouped by regions.

The 2002 subscriber penetration data show that all 18 Western European countries have

Table 3. Percentage of Digital Wireless Phone Subscribers and Handset Sales

Region	Country	Intro Yr	Subscribers (%)			Phone Sales (%)	
			1st Diff Yr	2002	Growth	2003	2004
Africa	Egypt	1997	0.1 %	7 %	167 %	3 %	4 %
	Morocco	1994	0.02 %	21 %	175 %	6 %	7 %
	S. Africa	1994	1 %	30 %	57 %	4 %	4 %
Middle East	Iran	1994	0.02 %	3 %	117 %	NA	NA
	Jordan	1995	0.3 %	23 %	98 %	NA	NA
	Kuwait	1994	0.5 %	52 %	105 %	NA	NA
	S. Arabia	1996	1 %	23 %	72 %	4 %	4 %
	Turkey	1994	0.1 %	35 %	115 %	5 %	6 %
	UAE	1994	1 %	65 %	76 %	NA	NA
Asia Pacific	Australia	1994	0.2 %	64 %	165 %	9 %	9 %
	China	1994	0 %	16 %	2132 %	6 %	7 %
	HK	1993	1 %	94 %	112 %	46 %	28 %
	Indonesia	1994	0.01 %	5 %	169 %	3 %	5 %
	Japan	1993	1 %	64 %	125 %	30 %	32 %
	Korea	1996	2 %	68 %	126 %	26 %	34 %
	Malaysia	1995	1 %	37 %	96 %	11 %	8 %
	N. Z.	1995	0.3 %	47 %	142 %	10 %	10 %
	Philippines	1994	0.01 %	19 %	192 %	12 %	12 %
	Singapore	1993	0.2 %	80 %	155 %	32 %	43 %
	Thailand	1994	0.02 %	23 %	197 %	11 %	9 %
	Vietnam	1994	0.01 %	2 %	219 %	NA	NA
South Asia	India	1995	0.01 %	1 %	119 %	2 %	2 %
	Pakistan	1995	0 %	0.5 %	113 %	NA	NA
North America	Canada	1997	2 %	28 %	85 %	27 %	29 %
	U.S.	1995	0.02 %	43 %	475 %	32 %	35 %
Western Europe	Austria	1994	0.2 %	84 %	169 %	20 %	20 %
	Belgium	1994	1 %	79 %	88 %	30 %	37 %
	Denmark	1992	0.1 %	83 %	252 %	25 %	24 %
	Finland	1992	0.1 %	87 %	158 %	25 %	26 %
	France	1992	0 %	65 %	973 %	28 %	31 %
	Germany	1992	0.2 %	73 %	93 %	34 %	37 %
	Greece	1993	0.5 %	85 %	86 %	58 %	58 %
	Hungary	1994	1 %	68 %	77 %	16 %	10 %
	Iceland	1994	1 %	77 %	112 %	NA	NA
	Ireland	1995	1 %	76 %	122 %	27 %	27 %
	Italy	1993	0.01 %	85 %	339 %	34 %	39 %
	Lux'bourg	1993	1 %	106 %	71 %	NA	NA
	Neth'lands	1994	0.4 %	74 %	107 %	24 %	29 %
	Norway	1993	0.2 %	83 %	205 %	29 %	32 %
	Portugal	1992	0.1 %	83 %	118 %	40 %	41 %
	Sweden	1993	0.3 %	77 %	208 %	41 %	41 %
	Switz'land	1993	0.1 %	79 %	131 %	34 %	32 %
	U.K.	1993	0.04 %	84 %	417 %	30 %	36 %

Notes: We mentioned earlier that countries did not introduce digital wireless phones in the same year. The column in the table marked Intro Yr lists the years that countries started to provide digital wireless phone services. The column header 1st Diff Yr indicates the percentage of subscribers in the Intro Yr for a country. The column header Growth in this table means average annual growth rate. "NA" in the table entries indicates countries and years for which data on growth of subscribers were not available.
Source: Yearbook of Statistics (ITU, 2004b); Euromonitor, www.euromonitor.com

exceptionally high digital wireless phone penetration levels, ranging from 65% in France to 106% in Luxembourg. Other regions have a few countries that lead the rest. For example, South Africa (30%) is the leader in Africa; Kuwait (52%) and United Arab Emirates (65%) are the leaders in the Middle East; and Australia (64%), Hong Kong (94%), Japan (64%), Korea (68%), and Singapore (80%) dominate others in Asia. Interestingly, the U.S., which is considered to be the world leader in several other technologies (e.g., the Internet), does not have a high penetration of digital wireless phones. Some possible explanations offered in the literature are the multiple standards that are permitted, and the fact that phone users have to pay for incoming calls. These factors may slow down the wireless phone diffusion in the U.S. (Gruber, 1999). King and West (2002) suggest that the U.S. lag can be traced back to two related incidents: the failure of the AT&T Bell System to realize the significance of wireless phones, and the institutional failure of the traditional phone industry after the breakup of the AT&T Bell System to build a vision for a new wireless phone industry in the U.S.

Despite the impressive average annual growth of subscriber penetration across all countries—the lowest is 57% in South Africa and the highest is 2132% in China—there appear to be large gaps between countries with the highest and lowest subscriber penetrations in 2002. The highest subscriber penetration countries are Hong Kong (94%) and nine of 18 Western European countries: Luxembourg (106%), Denmark (93%), Finland (87%), Greece (85%), Italy (85%), Austria (84%), the United Kingdom (84%), Norway (83%), and Portugal (83%).

Other regions have countries with the lowest subscriber penetration. Those countries are Pakistan (0.5%), India (1%), Vietnam (2%), Iran (3%), Indonesia (5%), and Egypt (7%). The high correlations between the 2002 subscriber data and the 2003 and 2004 handset sales per 100 people (0.8 and 0.76, respectively) suggest that such gaps are likely to continue. However, there are some other reasons to suggest why the gap might not be as alarming as the subscriber penetration numbers suggest.

First, there is evidence that one wireless phone subscription is sometimes widely shared and even rented out in poor, rural areas of developing countries such as Bangladesh and South Africa (Economist, 2005). As a result, the actual number of subscribers in several developing countries may be slightly higher than officially reported.

Second, because of low trust and security in poorer countries, sellers often find other innovative ways to use wireless phone services to pay for goods and services (Economist, 2005). For example, to protect against thieves, Coca Cola Inc. in Zambia requests its distributors to pay for shipments, which can be ten times the average annual wage, by sending text messages from their phones. Such innovative ways to use digital wireless phones are different from what happens in the developed world. So we may see more of this kind of behavior driving the growth of wireless phone subscription in developing countries in the future.

Third, the six lowest subscriber penetration countries recently experienced triple-digit growth levels similar to those found in high penetration countries such as Austria, Finland, and Portugal, which already have a much larger installed base to build upon. They include 113% growth for Pakistan, 119% for India, 219% for Vietnam, 117% for Iran, 169% for Indonesia, and 167% for Egypt. If such growth is sustained in the future, the technology access gap in these countries will likely diminish. In sum, all the above-cited reasons seem to point to the same thing: a narrowing of the digital divide in wireless phone usage.

Pre-Empirical Analysis II: Digital Divide—Generational Penetration Gaps

We next evaluate generational penetration gaps measured by the extent of 2G, 2.5G and 3G penetrations shown in Table 4.

Table 4. Digital Wireless Phone Sales per 100 People, by Generation

Region	Country	Percentage of Phone Sales by Generation						
		2G			2.5G			3G
		1999	2004	Growth	2002	2004	Growth	2004
Africa	Egypt	1 %	4 %	50 %	-	-	-	-
	Morocco	1 %	7 %	130 %	-	-	-	-
	S. Africa	6 %	4 %	3 %	-	-	-	-
Middle East	Iran	NA	NA	NA	NA	NA	NA	NA
	Jordan	NA	NA	NA	NA	NA	NA	NA
	Kuwait	NA	NA	NA	NA	NA	NA	NA
	S. Arabia	4 %	9 %	24 %	-	-	-	-
	Turkey	5 %	3 %	2 %	1 %	2 %	173 %	-
	UAE	NA	NA	NA	NA	NA		NA
Asia Pacific	Australia	8 %	5 %	-6 %	1 %	4 %	2831 %	1 %
	China	2 %	4 %	25 %	0.1 %	3 %	269 %	0.2 %
	HK	22 %	7 %	-5 %	17 %	20 %	195 %	1 %
	Indonesia	0.2 %	3 %	86 %	0.3 %	2 %	3247 %	0.4 %
	Japan	24 %	11 %	-11 %	9 %	11 %	7 %	9 %
	Korea	28 %	0.1 %	-54 %	17 %	8 %	-31 %	26 %
	Malaysia	4 %	4 %	39 %	1 %	3 %	2104 %	1 %
	N. Z.	12 %	5 %	-0.1 %	2 %	4 %	5775 %	1 %
	Philippines	3 %	6 %	34 %	0.3 %	5 %	3011 %	1 %
	Singapore	15 %	11 %	31 %	15 %	30 %	44 %	1 %
	Thailand	1 %	2 %	104 %	14 %	6 %	286 %	0.3 %
	Vietnam	NA	NA	NA	NA	NA	NA	NA
South Asia	India	0.1 %	0.4 %	68 %	0.05 %	2 %	923 %	-
	Pakistan	NA	NA	NA	NA	NA	NA	NA
North America	Canada	12 %	12 %	6 %	2 %	11 %	184 %	6 %
	U.S.	12 %	15 %	9 %	2 %	14 %	206 %	7 %
Western Europe	Austria	28 %	11 %	-13 %	3 %	8 %	121 %	1 %
	Belgium	21 %	20 %	5 %	5 %	15 %	90 %	2 %
	Denmark	17 %	13 %	-2 %	4 %	10 %	118 %	2 %
	Finland	17 %	14 %	-3 %	4 %	11 %	119 %	2 %
	France	22 %	7 %	-17 %	7 %	24 %	177 %	0.4 %
	Germany	21 %	12 %	-4 %	9 %	24 %	186 %	1 %
	Greece	25 %	31 %	9 %	9 %	24 %	109 %	4 %
	Hungary	6 %	9 %	30 %	1 %	1 %	10 %	0.1 %
	Iceland	NA	NA	NA	NA	NA	NA	NA
	Ireland	30 %	15 %	-10 %	5 %	11 %	82 %	2 %
	Italy	25 %	8 %	-16 %	12 %	30 %	193 %	1 %
	Lux'bourg	NA	NA	NA	NA	NA	NA	NA
	Neth'lands	22 %	15 %	-5 %	3 %	12 %	121 %	2 %
	Norway	26 %	17 %	-7 %	4 %	13 %	142 %	2 %
	Portugal	27 %	22 %	-1 %	7 %	17 %	97 %	3 %
	Sweden	23 %	22 %	2 %	7 %	17 %	154 %	3 %
	Switz'land	27 %	17 %	-6 %	5 %	13 %	104 %	2 %
	U.K.	29 %	7 %	-19 %	13 %	25 %	211 %	5 %

Notes : The column header Growth in this table means average annual growth rate. "NA" in the table entries indicates countries and years for which data on phone sales and growth of subscribers were not available.
Source: Euromonitor, www.euromonitor.com

Retail sales of handsets offer strong evidence of inequality in value gained from wireless phone usage across countries. Depending on the growth of 2G, 2.5G, and 3G, most countries can be divided into three groups. (See Table 5 for a country list.) We refer to the first group of countries as the advanced group. They are already experiencing sharp increases in 2.5G and 3G sales, and a decline in 2G handset sales. The second group is the transition group. They are experiencing growth in all three generations, albeit with somewhat slower growth in 2G handset sales. The last group of countries is the emerging group. They are just beginning with 2.5G or 3G service, or they have yet to begin. Such differences in the growth of 2.5G and 3G handset sales prevent people and businesses from reaping benefits from the high-speed data services available on 2.5G and 3G networks. Examples are real-time information updates, Internet browsing, multimedia messaging, and wireless banking.

Table 5. Countries Grouped by the Extent of Penetration for 2G, 2.5G, 3G

Advanced Group		Transition Group		Emerging Group
Growth in 2.5G and 3G and Decline in 2G		Growth in All Three Generations		No 2.5G and/or 3G
Australia	Japan	Belgium	Malaysia	Egypt
Austria	Korea	Canada	Philippines	Iran
Denmark	Northlands	China	Singapore	Morocco
Finland	New Zealand	Greece	Sweden	Pakistan
France	Norway	Hungary	Thailand	Saudi Arabia
Germany	Portugal	India	U.S.	South Africa
Hong Kong	Switzerland	Indonesia		Vietnam
Ireland	U.K.			
Italy				

In summary, the evidence from subscriber penetration data and handset sales across the wireless generations provides support for access and usage gaps across countries. Although it is likely that the subscriber penetration gaps between regions and countries may be narrowing in the future, we expect that the generational penetration gaps will persist. Moreover, there will probably be technological gaps even in the presence of new digital wireless communication technologies, despite the fact that the emerging 4G technologies will subsequently replace the older digital wireless phone technology generations in selected regions (e.g., Western Europe) and countries (e.g., Japan, Korea). Currently, the primary usage of digital wireless phones in developing countries is for voice communication. Its wide adoption as a substitute for fixed-line phones reported in several countries is largely driven by poor land-line infrastructure and services. So, it will take at least a few years for those countries to catch up with demands to use advanced data applications enabled by the 3G and later generations of digital wireless phone technology.

Panel Data: Explaining the “Wireless Digital Divide”

We next present a panel data econometrics model analysis of the within-country drivers to explain digital wireless phone diffusion. The model helps us to explain fast growth when it is observed, and provides insights about the public policy variables that may be actionable for regulators, if they wish to improve adoption. The results we obtain help us to provide insights on factors that are associated with the digital divide and, perhaps more importantly, provide policymakers with some useful input on how to bridge the observed gaps.

Model Setup: Panel Data Model Preliminaries and Formulation

We use a fixed-effects panel data model to test the explanatory factors for digital wireless phone adoption: $y_i = \alpha + \beta X_{it} + u_i + \varepsilon_{it}$, where $i = 1,\ldots, I$ denotes countries and $t = 1,\ldots,T_i$ denotes diffusion years. Since the countries did not begin their digital wireless phone implementation in the same year, the number of data points differs across countries, resulting in an unbalanced panel of data. For example, Australia, which began its adoption of digital wireless phone technology in 1994, has nine data points. Denmark began its adoption in 1992 and has eleven data points. The dependent variable, y, is stated as an *annual subscription penetration rate* for the technology. α is an intercept, the vector X is a set of within country variables, and the β's are the estimated coefficients. u_i are country-specific effects, and ε_{it} are zero mean, homoskedastic error terms. They are uncorrelated with one another and uncorrelated with the explanatory variables.

Panel Data Model Results

We will attempt to test the influence of five within country variables on the diffusion of digital wireless phones. Those five variables are wealth (GNP), telecommunication infrastructure (PHONE), market competition (COMP), the access cost (COST), and standards (STD).

Estimation Issues. We used STATA 8.0 to estimate the models. Similar to ordinary least square (OLS) regression, multicollinearity and heteroskedasticity are important information structure anomalies that need to be carefully tested before running the model. Multicollinearity in panel data models can increase the variance of the estimated parameters. This makes the estimates less precise, and depowers the hypothesis tests [Kennedy, 2003]. In contrast, heteroskedasticity will likely lead to incorrect, often underestimated, values for the standard errors. We use *variance inflation factor* (VIF) analysis given by $1/(1-R_i^2)$, where R_i^2 is obtained from regressing explanatory variable i on all other independent variables to determine whether multicollinearity is a problem. The presence of multicollinearity is indicated by VIFs greater than 10[Kennedy, 2003]. We checked for pair-wise correlation between the explanatory variables. Typically, correlation coefficients of 0.7 or more are considered to be high. All of our explanatory variables have correlation coefficients less than 0.7, except *GDP* and *PHONE* at 0.9.[5] Thus, we chose to keep PHONE and drop GDP from the main model. The latter is a key variable that differentiates developed from developing countries. In addition, since we will perform sub-sample analysis to test the differences of within-country drivers between developed and developing countries, we believe that the influence of GDP can be inferred from those results. All VIF values are less than 10 (ranging from 1.12 for PRICE to 5.55 for PHONE), indicating that multicollinearity is not an issue.

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[5] Thus we see that wealth and infrastructure tend to go hand-in-hand: wealthy countries typically have well-developed technology infrastructures. So it is not possible with this data set to discriminate between diffusion growth effects that are attributable to wealth and infrastructure separately; we can only use one of the two of them for our estimation. As a result, the effects that we actually will show for the country wealth-related variable are likely to be similar to the effects we would show for country infrastructure, if we only included that variable.

We use the Breusch-Pagan (1979) χ^2 test to determine whether heteroskedasticity is an issue. The test result ($\chi^2 = 55.44$, d.f.=1, p=0.00) prompts us to reject homoskedasticity. At least three approaches can be applied to correct for heteroskedasticity [Kennedy, 2003]: *transformation of the dependent variable*, use of *weighted least squares*, or use of *robust standard errors*. We chose the robust standard error approach due to weaknesses in the other techniques and its common use today (Stock and Watson, 2002).[6]

Within-Country Effects. We used four within-country explanatory variables (PHONE, OPR, PRICE, and STD) to fit the fixed-effects panel data model. Table 6 presents the results of the fixed-effects model.

Table 6. Results of Panel Data Models for Wireless Phone Subscription

Variables	Fixed-Effects Model		
	Coefficient	Robust Std. Errors	t –Value
PHONE	0.0007	0.00008	8.14***
OPR	0.026	0.005	5.62***
PRICE	-0.00004	0.00002	-2.00**
STD	-0.033	0.10	-3.39***

Notes: 384 observations. Dependent variable is the *annual subscription penetration rate* for digital wireless phone technology in a country. $R^2 = 0.51$ for fixed-effects panel data regression. The *F*-statistics that test for whether the coefficients of the explanatory variables are all equal to zero is 49.78 ($p = 0.00$), indicating a high level of significance. In addition, the *F*-statistics that test for whether the country-specific effects are all equal to zero is 3.81 (p = 0.00), also indicating a high level of significance. The significance levels are: * =p<.10, ** = p < .05, and *** = p < .01.

Based on the estimated coefficients in the model, all variables show significant results. Therefore, Hypotheses 2 to 5 dealing with within-country determinants of digital wireless phone diffusion are supported. The coefficient of *PHONE* is positive and significant ($\beta_{PHONE} = 0.0007$, $p < .01$). Thus, the Infrastructure Hypothesis (H2) is supported. This means that a unit increase in the number of fixed-phone lines per 1,000 people increases the subscription penetration rate by 0.07%. The coefficient of *OPR* is positive and highly significant ($\beta_{OPR} = 0.026$, $p < .01$), which supports the Market Competition Hypothesis (H3). This indicates that an additional operator doing business in the digital wireless phone market increases the subscription rate observed in the market by a little more than 2%. The coefficient of *PRICE* is negative and significant ($\beta_{PRICE} = -0.00004$, $p < .05$), and this is a logical result. But the Access Cost Hypothesis (H4) is not strongly supported. The magnitude of the coefficient of *PRICE* is close to zero and negative. This indicates that a one unit increase in price decreases the subscription rate by a mere 0.004%—in other words, very little. Finally, the coefficient of *STD* is negative and highly significant ($\beta_{STD} = -0.033$, $p < .01$), which supports the Standards Hypothesis (H5). An additional digital wireless standard in a country decreases the subscription rate by 3.3%.

Level of Development. To evaluate whether the strength of within-country variables

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[6] There are two problems with the transformation of a dependent variable: (1) A suitable transformation may not be easy to find, and (2) the transformed variable makes it more difficult to interpret and understand the results. Similarly, for the weighted least squares, the weight that is selected depends on whether the source of the heteroskedastic errors is known or not known.

differs between developed and developing countries, we stratified the data set into two groups: developed countries (n = 28) and developing countries (n = 15). Then we performed sub-sample analysis using the panel data model. Table 7 presents the results.

Table 7. Results of Stratification Analysis in the Panel Data Model

Variable	Developed Countries			Developing Countries		
	Coeff.	Robust Std. Errors	t-Value	Coeff.	Robust Std. Errors	t -Value
PHONE	0.0006	0.0001	6.02***	0.0006	0.0001	5.33***
OPR	0.032	0.006	4.90***	0.017	0.005	3.48***
PRICE	-0.00002	0.00009	-0.23	-0.00003	0.00002	-1.28
STD	-0.02	0.01	-1.40	-0.03	0.01	-3.17***

Notes on developed country model: 259 observations. Dependent variable is the *annual subscription penetration rate* for digital wireless phone technology in a country. $R^2 = 0.41$ for fixed-effects regression. *F*-statistic that tests if coefficients of the explanatory variables are all equal to zero is 33.72 ($p = 0.00$), indicating a high level of significance. In addition, *F*-statistic to test if country-specific effects are all equal to zero is 4.0 ($p = 0.00$), indicating high significance.

Notes on developing country model: 125 observations. Dependent variable is the *annual subscription penetration rate* for digital wireless phone technology. $R^2 = 0.63$ for fixed-effects regression. *F*-statistic that tests if the coefficients of the explanatory variables are all equal to zero is 23.4 ($p = 0.00$), indicating a high level of significance. *F*-statistic that tests for whether the country-specific effects are all equal to zero is 3.21 ($p = 0.00$), indicating high significance.

Other notes: The significance levels are: * = p < .10, ** = p < .05, and *** = p < .01.

In the developed country sub-sample, *PHONE* ($\beta_{PHONE} = 0.0006$, $p < .01$) and *OPR* ($\beta_{OPR} = 0.032$, $p < .01$) are positive and significant. In the developing country sub-sample, *PHONE* ($\beta_{PHONE} = 0.0006$, $p < .01$), *OPR* ($\beta_{OPR} = 0.017$, $p < .01$), and *STD* ($\beta_{STD} = -0.03$, $p < .01$) are positive and significant. The results reveal a few differences with the influence of within-country factors between developed and developing countries. First, developing countries are more sensitive to the impact of multiple standards on the dynamics of diffusion. Second, the magnitude of the effect of OPR for developed countries - the number of digital wireless operators, which measures market competition - is almost three times that of the developing countries. Since the variable PRICE is not significant in both models, this indicates that non-price competition is a stronger driver of diffusion growth in developed countries than in developing countries. These results provide evidence to support the International Influences Hypothesis (H7).

Contagion Analysis of Regional Influences

We now shift to consider how regional influences affect the global diffusion of digital wireless phones at the country level of analysis. We capture the regional contagion effects, which we define as the extent of the influence of other countries in the region on the diffusion of a country of interest. In this section, we employ a vector autoregression model (VAR) and a variance decomposition (VDC) technique that permit us to obtain a reading on the extent to which wireless diffusion in one country is driven by wireless diffusion or other related factors in other countries.

Setup: Vector Autoregression and Variance Decomposition Modeling

We begin with a brief explanation of our rationale for using a VAR model. A *vector autoregression model* is a system of equations with lagged values of the dependent variables used as independent variables. A VAR model's structure is $y_t = \alpha + \sum_{l=1}^{L} \beta_{t-l} y_{t-l} + \varepsilon_t$, where y is an n x 1 vector of variables including both dependent and independent variables, α is an n x 1 vector of deterministic components, β is an n x n matrix of coefficients, ε is an n x 1 vector of residuals, t is the year, and l is the lag length.

Proposed by Sims (1980), VAR methods have been widely used to study macroeconomic issues, including the relationship between the United States aggregate and individual states' economies (Sherwood-Call, 1988), the economic impacts of equity markets (Rousseau and Wachtel, 2000), and forecasts of the unemployment rate and the rate of growth in gross domestic product (Robertson and Tallman, 1999). VAR models explore statistical regularities in historical data. They don't require assumptions about the underlying economic structure. As a result, this methodology enables researchers to explore dynamic behaviors among economic variables without imposing unnecessary theoretical biases or specifying a structural model.

VAR Model Specification

We employ a modified version of the VAR system discussed by Sherwood-Call (1988) and Kauffman and Wang (1995) to investigate the relationship between subscriber growth at two levels: the country and the region. In the regional equation, regional subscriber growth rate is a function of its own lagged values of growth. For each country equation, country subscriber growth rate is a function of its own lagged values of growth, as well as those at the regional level. Consider Western Europe, for example, with 18 countries in our sample. As a result, the regional equation uses the combined annual subscriber growth and their lags from all the 18 countries as the dependent and explanatory variables, respectively, in the model. At the country level, each of the 18 equations uses its own country's annual subscriber growth rate as the dependent variable, and lags of the country's annual subscriber growth rate and the lags of Western Europe's annual subscriber growth rate as the explanatory variables. Similar representations support the exploration of linkages between subscriber growth at the country and other regional levels, to the extent that our data can support such analysis with enough observations.

The regional equation can be written as:

$$REGION_t = \alpha + \sum_{l=1}^{L} \beta_{t-l} REGION_{t-l} + \varepsilon_t \qquad \textbf{(Regional Equation)}$$

where $REGION_t$ is regional-level wireless subscriber growth at time t, α is an intercept, and the β's are VAR coefficients, and ε_t is the error term. The *country equation* can be written as follows:

$$COUNTRY_t = \lambda + \sum_{l=1}^{L} \gamma_{t-l} REGION_{t-l} + \sum_{l}^{L} \delta_{t-l} COUNTRY_{t-l} + \xi_t \qquad \textbf{(Country Equation)}$$

where $COUNTRY_t$ is country-level wireless subscriber growth at time t, λ is an intercept, and γ and δ are VAR coefficients. Once again, ξ_t is the error term.

Variance Decomposition to Understand the VAR Error Terms

Most VAR models have a large number of coefficients and involve lagged variables, so the number of parameters increases substantially when a variable is added to the model.[7] Such a large number of coefficients and the complicated dynamics of their relationships make it difficult to interpret and draw implications from the estimated coefficients. Instead, the variance decomposition technique is commonly used to attribute the total estimated errors—or shocks—to changes in the values of each variable. The economics literature uses the word shock to imply a random event of forecast significance to a time series. See Cochrane (1994), Loo and Lastrapes (1998), and Stock and Watson (2001), who offer multiple applications. We apply this method here as well.

The error term in the regional equation represents the extent to which actual regional subscriber growth deviates from the estimate. When such a deviation occurs, it is indicative of a regional shock. Since the regional and country equations are linked through the lagged values of the regional subscriber growth rates in the country equation, the error term in the country equation will reflect the shocks that occur at both the country and the regional levels. So the observed deviation from the actual values in the country equation can be decomposed into the portion that is attributable to regional shocks and another portion that is attributable to country shocks.

A regional contagion link represents the regional component of the variance decomposition for each country. This value is used to measure the strength of linkage or co-movement between digital wireless phone diffusion at the country and regional levels. A high regional contagion link value means that most subscriber growth at the country level is associated with shocks at the regional level. But, if a country's fluctuations in the growth of digital wireless diffusion result from shocks to the country's diffusion growth, not shocks to regional diffusion growth, that country will have a low regional contagion link value. In other words, the regional contagion effect (the influence of other countries in the region) will be weaker in that country.

Data

Although we have digital wireless phone subscriber data in five regions, we only will investigate regional contagion effects in Asia Pacific and Western Europe regions in this study. Why? First, our sample covers a relatively large number of countries in those regions: 18 and 12 countries in Western Europe and Asia Pacific, respectively. We have fewer degrees of freedom to conduct the analysis on the other regions due to a lack of data. Second, the rapid subscriber growth observed in several countries in these regions makes them a good empirical case study. From these contexts, we can draw interesting insights and implications from our analysis for future diffusion growth in other regions of the world, especially the developing world.

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[7] For example, a VAR system that has nine variables and four lags has nine equations, each of which has 37 parameters (one intercept, four coefficients of its own lagged variable, and 32 coefficients from the lags of the other eight variables), resulting in 333 total unknown parameters.

Since our VAR models use lagged data to analyze the relationship between regional and country subscriber growth, the degrees of freedom are reduced as we introduce lags into the model. This is a sensitive issue in our data set. First, unlike other macroeconomic data that are often available monthly or quarterly, our observations are measured on an annual basis. As a result, we have a limited number of observations. Second, the fact that countries did not start their diffusion at the same time makes the digital wireless phone subscriber growth time series even shorter for some countries. The maximum number of observations is 11 for countries such as Finland, France and Germany, whose digital wireless phone diffusion began in 1992. The minimum number of observations is eight for countries such as Malaysia, New Zealand, and Ireland, whose digital wireless phone diffusion only started later in 1995.

To achieve confidence with our model estimation, we need to have a longer time series of subscriber growth to parameterize the models. So we use time series of combined analog and digital wireless phone subscriber data, which became available in 1986 in Western Europe and 1987 in Asia Pacific. A lack of data in some countries forced us to drop them from our analysis. After these steps, our Western European data set has annual analog and digital subscribers from 1986 to 2002 for 14 countries. Our Asia Pacific data set has annual analog and digital subscriber data from 1987 to 2002 for 10 countries. [8] Next, we calculated annual subscriber growth for all countries and regions. This resulted in 16 observations for Western Europe and 15 for Asia Pacific.

Estimation Results

We used STATA 8.0 to estimate our VAR models, which requires the explicit choice of lag-length. Our choice of four-, three-, two- and one-period lag-lengths is based on several model selection criteria that consider the tradeoff between fit and complexity. Since our goal is to obtain estimates for the regional contagion links from the variance decomposition, we do not place a strong emphasis on obtaining "accurate" parameter estimates in our VAR models. Instead, analysis of the residuals is key. So we believe it is acceptable to employ VAR in the manner that we have discussed. For additional information, the interested reader should see Sherwood-Call (1988). Table 8 presents the results for VAR model fit using standard fit statistics and modeling diagnostics (Hamilton, 1994).

All of the regional and country VAR models show a good fit. The Western Europe and Asia Pacific regional equations had R^2 = 0.71 and R^2 = 0.77, respectively. The R^2s for the Western European country equations ranged from R^2 =0.56 for Germany to R^2 =0.99 for Belgium. In addition, all of the Asia Pacific country equations have a good fit, ranging from R^2 =0.74 for Korea to R^2 = 0.99 in Australia and Thailand. We rejected the null hypothesis that the coefficients for the lagged variables were zero, except for the Germany, Sweden, Korea, and Singapore equations.

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[8] The Western European countries in the VAR data set include Austria, Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Sweden, and UK. The Asia Pacific countries include Australia, China, Hong Kong, Indonesia, Japan, Korea, Malaysia, New Zealand, Singapore, and Thailand.

Table 8. VAR Results for Western Europe and Asia Pacific Regional and Country Digital Wireless Subscriber Growth

Country	R^2	F–Stat.	Country	R^2	F -Stat.
Western Europe Equation			Asia Pacific Equation		
0.71		7.30**	0.77		9.37***
Country Equation			Country Equation		
Austria	0.92	18.45**	Australia	0.99	254.40***
Belgium	0.99	239.46***	China	0.91	13.86*
Denmark	0.92	18.08**	Hong Kong	0.90	12.37*
Finland	0.88	10.73**	Indonesia	0.97	50.09**
France	0.81	6.32*	Japan	0.96	37.35**
Germany	0.56	1.92	Korea	0.74	3.83
Iceland	0.81	6.51*	Malaysia	0.92	16.42*
Ireland	0.93	19.79**	New Zealand	0.98	90.55**
Italy	0.96	37.47***	Singapore	0.75	4.10
Luxembourg	0.80	5.95*	Thailand	0.99	143.65***
Netherlands	0.79	5.66*			
Norway	0.88	10.66**			
Sweden	0.71	3.72			
U.K.	0.89	12.59**			

Note: Model = vector autoregression. Dependent variable is regional wireless subscriber growth at time *t* for the Western Europe and Asia Pacific Region equations. Dependent variable is country-level wireless subscriber growth at time *t* for the individual country equations. R^2s indicate model fit. *F* statistics test the hypothesis that all model parameters are zero. All models were estimated with four lagged variables with $l \in \{0,1,2,3,4\}$: four regional subscriber lags in the regional equation, and four regional and country subscriber lags in the country equations. We used multiple statistics for selecting the maximum length lag. They are: (1) the *likelihood ratio test criterion* (LR), (2) the *final prediction error criterion*, (3) the *Akaike information criterion*, (4) the *Schwartz information criterion*, and (5) the *Hannan-Quinn information criterion*. Our choice of a four-period lag is supported by at least two of selection measures for 11 Western European country equations. Exceptions were Finland, Netherlands, and Norway; the selection criteria suggest models with three-period lags. Similarly, a four-period lag is supported by at least three criteria in all Asia Pacific country equations. We also used the *Granger* [1969] *causality statistic* to see if lagged values of regional subscriber growth have explanatory and predictive power for country subscriber growth. We checked to see if the *Granger causality Wald* χ^2 *statistics test* for all coefficients of regional subscriber growth lags in country equations were equal to zero. All χ^2s were significant, but those for Austria, Korea, and Netherlands. Reported significance levels are: $^{*} = p < .10$, $^{**} = p < .05$, $^{***} = p < .01$.

Next, we apply the variance decomposition approach to the forecast error variance in all of the country equations. The country subscriber growth forecast error variance is attributed to two sources: country shocks and regional shocks. The latter is our regional contagion links. The regional contagion links are defined as percentages representing the regional shock component of the variance decomposition. We report them in Table9.

There appear to be varying strengths of regional contagion links among the different Western European and Asia Pacific countries. The countries fall into three groups: those with high, medium, and low regional contagion links. The Asia Pacific countries reveal a pattern of homogeneously high regional contagion links, while Western European countries are almost equally divided across the three groups. In Western Europe, five countries associated with high regional contagion links are Austria (74), Belgium (73), Iceland (94), Italy (90), and the Netherlands (69). The set of countries associated with medium regional contagion links includes Denmark (58), France (58), Germany (57),

Table 9. Regional Contagion Links from Variance Decomposition Analysis

Country	Regional Contagion Link	Country	Regional Contagion Link
Western Europe		Asia Pacific	
Austria	74	Australia	94
Belgium	73	China	89
Denmark	58	Hong Kong	98
Finland	17	Indonesia	56
France	58	Japan	96
Germany	57	Korea	99
Iceland	94	Malaysia	13
Ireland	2	N.Z.	88
Italy	90	Singapore	87
Lux'bourg	9	Thailand	95
Neth'lands	69		
Norway	31		
Sweden	51		
U.K.	46		

Note: No dependent variable or independent variables were used for this analysis. Instead, we used variance decomposition analysis to obtain the results. The procedure is described in Hamilton (1994) and Sherwood-Call (1988). The regional contagion links are the components of variance calculated from the two-year forecast associated with the regional shocks to wireless phone diffusion. A high value for a regional contagion link means that most subscriber growth at the country level is associated with shocks at the regional level, and is suggestive of a strong contagion effect. A low value for a regional contagion link means that most of the country's subscriber growth is not associated with shocks at the regional level.

Sweden (51), and the United Kingdom (46). The low regional contagion-linked countries are Finland (17), Ireland (2), and Luxembourg (9). Among the Asia Pacific countries, eight countries—including Australia (94), China (89), Hong Kong (98), Japan (96), Korea (99), New Zealand (88), Singapore (87) and Thailand (95)—reveal high regional contagion links. Indonesia (56) and Malaysia (13) have medium and low links, respectively.

Discussion

We previously examined the digital divide with two measurement perspectives: subscriber penetration gaps and generational penetration gaps. Our analysis revealed that wireless digital divides exist to varying degrees between various regions and across a large number of countries. We next discuss our panel data and VAR/VDC regional contagion link analyses in greater detail.

Drivers of Wireless Diffusion: Explain Country-Level Digital Divide

We examined wireless digital divides in the global market with a focus on the access and usage gaps across countries and regions. We learned that in terms of subscriber penetration, Western Europe and a selected group of Asia Pacific countries were the leaders, followed by North America and the Middle East, with Africa and South Asia taking up the rear. With the exception of the North American countries, the regional and country-wide patterns of digital divides in digital wireless phone technology seemed similar to other ITs, such as the Internet. A widely-cited survey of Internet users by

NUA.com (2002) reported similar patterns for the number of Internet users in various global regions in 2002.

Similarly, we also found evidence of gaps associated with 2G, 2.5G, and 3G penetration across the countries. In particular, Western Europe and selected countries in the Asia Pacific region appear to be earlier adopters of 2.5G and 3G technologies. Countries and regions that have low subscriber penetrations also lag behind and fail to benefit from advanced data applications of wireless phones. The lack of content developers and the relatively low sophistication of users may prevent operators from launching these new services. The countries and regions appear not to be too conducive to the operators conducting profitable business. However, being a technological laggard is not always a problem. Some countries can benefit by leapfrogging and skipping obsolete technologies altogether, as in the case of South Africa.

But will the digital divide narrow in the future? We use the results of our panel data model to predict the five-year subscriber penetrations. To get a sense of the gaps, we chose to examine two relatively high penetration countries (Japan and the U.S.) and two low penetration countries (India and Indonesia).[9] Figure 3 shows digital wireless phone

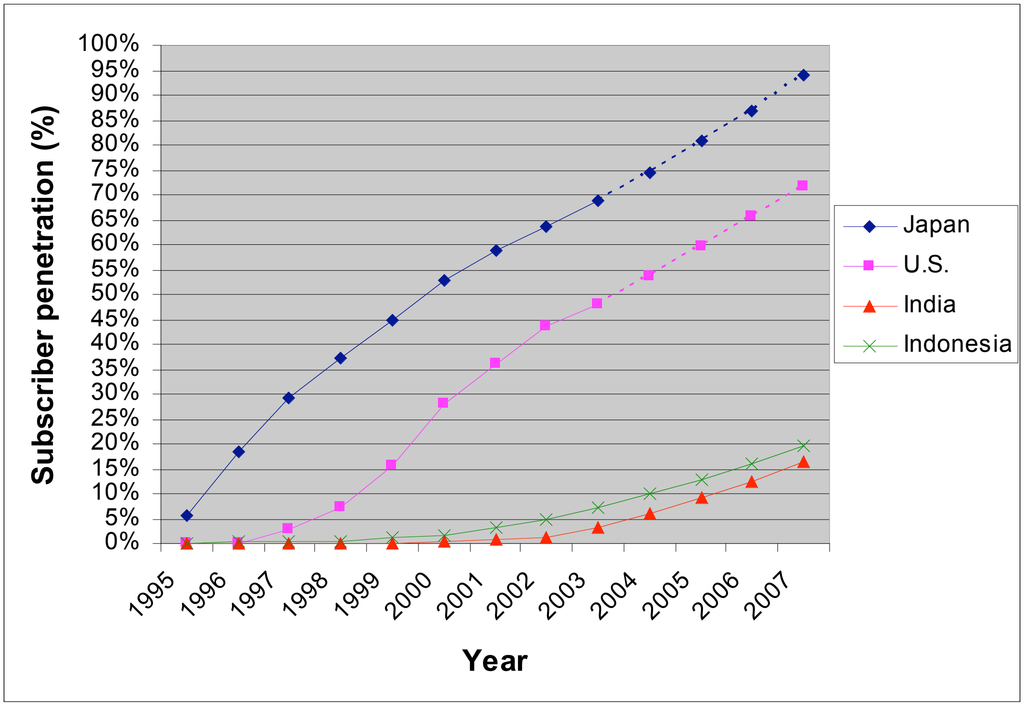

Figure 3. Five-Year Prediction: Digital Wireless Phone Subscription

Note: The solid lines show the actual subscriber growth in Japan, the U.S., India, and Indonesia from 1995 to 2002. The dotted lines show the predicted trajectories of the subscription growth from 2003 to 2007.

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[9] Our panel data model was specified as an explanatory model. We did not set out to accurately predict the extent of wireless phone diffusion. So there are no parameters in our model that build in an upper-bound on growth. As a result, our diffusion growth projections might not be as accurate as those we might have obtained had we developed alternative models for prediction.

subscriber penetration, with 1995 to 2002 plots of actual data and 2003 to 2007 plots of predicted data.

Our prediction suggests that digital wireless phone diffusion will continue in all four countries. However, growth is relatively faster in the low penetration countries. India and Indonesia exhibited average growth of 85% and 32% per year, while the United States and Canada had average growth of 11% and 8%. These growths seem to suggest that the digital divide associated with subscriber penetration is likely to diminish.

Our fixed-effects results also help to explain some key within-country factors that seem to influence wireless subscription rates, leading to the observed digital divides. Consistent with previous studies (e.g., Hargittai, 1999), we found that the low telecommunication infrastructure penetration appears to slow down diffusion. In addition, the extent of non-price and price competition is substantial, and it likely drives diffusion. Finally, multiple standards tend to slow down adoption. Our results confirm the prior findings of Kauffman and Techatassanasoontorn (2004 and 2005), who used duration models to examine similar issues in cross-national digital wireless phone diffusion using panel data. Countries that have greater wireless competition, with more digital wireless operators and more fixed-phone lines, tend to exhibit faster adoption rates.

We also found that the importance of two other factors, market competition and the number of standards, differs across developed and developing countries. Specifically, the influence of market competition appears to be stronger in developed countries than in developing countries. Such a difference could be explained by the usage gap across developed and developing countries. As suggested by our analysis of the subscriber and generational penetration gaps, most developing countries have experienced faster growth of the 2G generation technologies, but much slower growth of 2.5G and 3G generations. Prior studies (e.g., Waverman et al., 2005) suggest that several developing countries use wireless phones as a substitute for basic voice communications. As a result, market competition in which operators compete to offer novel data services (e.g., wireless banking, wireless TV) is less important in those economies.

In contrast, standards are more important in developing countries compared to developed countries. There are two plausible explanations for this finding. First, subscribers in developing countries may be less sophisticated than those in developed countries. As a result, they may be confused by various digital wireless phone standards, which deter them from adopting, compared to those in developed countries. Second, slow diffusion may give digital wireless operators less economic and profit incentive to provide interoperating services across the different standards.

Country Diffusion Co-Movement and the Regional Wireless Digital Divide

The preliminary analysis of the digital divide offers evidence that regional contagion effects in varying strengths enable countries in the same region to share similar adoption and diffusion patterns. It is important to know their magnitude and direction, in addition to within-country diffusion parameters, to understand the dynamics of the global digital divide for digital wireless phones.

Explaining the Regional Contagion Effects

Interestingly, we found that there are regional contagion effects–how countries within the same region influence each other on diffusion. There are a number of reasons for the wireless phone diffusion to exhibit regional contagion effects,-in addition to the explanation offered by simple geographical proximity. Geographical proximity proxies for a number of underlying factors that may be correlated. For example, different regions of the world exhibit different economic regimes (Mussa et al., 2000; World Bank, 2004a). As a result, there is often alignment across countries in a geographical region in terms of their roles as manufactured or agricultural commodities producers, production for export-focused versus consumption from imports-focused economies, and knowledge creation-centered versus natural resources exploitation-centered economies (World Bank, 2004b). A second dimension may explain the regional contagion effects that we observed: cultural similarity. Cultural similarities predispose the countries in a region that share them to react to similar external forces in a patterned way (Gruber and Verboven, 2001a). The success of digital wireless phones and their personalizing elements (e.g., customized chimes, music to identify a caller, sharing of music, and so on) in Japan, Korea, Taiwan, and Hong Kong offers a good case in point relative to the 3G wireless technologies (Dholakia et al., 2002; Lehrer et al., 2002). These ancillary services have come to be highly profitable for both operators and service providers among young adopters—and the facts about this high profitability have come to be known both inside and outside the Asia Pacific and East Asian region. They have been of less interest outside this region, where cultural differences in the youth market prevail.

The regional contagion links suggest an interesting pattern of regional influences on a country's digital wireless phone subscriber growth. The links also provide an explanation of the extent to which a country's subscriber growth is closely aligned with changes in regional subscriber growth and in regional economic developments. For a better understanding of why some countries within the same region are subject to stronger regional contagion effects than others, we can use findings from other studies to support our interpretation of the regional contagion link results, and corroborate specific findings.

Why Are There Different Degrees of Regional Contagion Effects?

There are several underlying factors that the may explain the different degrees of regional contagion effects that we observed. One is cross-border interaction. Countries that have high individual levels of interaction with other countries are likely to experience high regional contagion effects. For example, Putsis et al. (1997), in their diffusion analysis of four products among European nations, showed that Austria, Denmark, France, Germany, Italy, the Netherlands, and Sweden have patterns of technology diffusion and adoption that are driven by higher external contact rates than other countries in the region. These European countries are associated with medium to high regional contagion links in our study, in synch with Putsis et al.'s (1997) findings.

Another plausible explanation is drawn from the economics literature: international trade and foreign investments create learning externalities (e.g., Eaton and Kortum, 2002; Keller, 2004). These spillovers can influence technology diffusion among the countries involved. In the wireless phone industry, interlocking ownership; joint ventures; and consultancy, training, and technology and knowledge transfer agreements among wireless phone businesses in various countries are likely to result in stronger regional contagion linkages in diffusion growth.

Illustrations of Regional Contagion Links for Diffusion Co-Movement

To illustrate, Figure 4 shows ownership and business relationships among wireless phone operators in the Asia Pacific region, which help to substantiate the story that the VAR/VDC analysis results suggest.

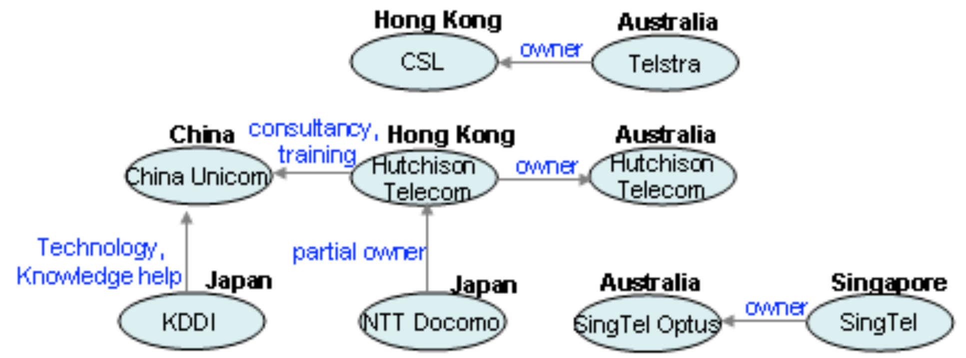

Figure 4. Selected Linkages among Wireless Phone Operators in Australia, China, Hong Kong, Japan, and Singapore

Note: We constructed the bilateral relationships between operators from information presented in various Gartner Research Group publications. The direction of an arrow depicts the source of funds or financial or technology assistance. These actual bilateral relationships are suggestive of the kinds of activities that may substantiate the regional contagion links that we have reported.

The reader should note the extent of interlocking ownership that seems to be present in Asia Pacific wireless telecommunication. Specifically, we see that Hong Kong's Hutchison Telecom has foreign direct investment from Japan's pioneering NTT Docomo. But Hutchinson Telecom also owns Australia's Hutchison Telecom. These foreign direct investments suggest that additional revenue from strong diffusion growth in one country will be likely to bring in additional revenues representing growth in another country. (A similar argument applies when the markets experience slow growth.) Similarly, other bilateral relationships such as consultancy, training, and knowledge transfer agreements enable the operator on the receiving end of the agreement to gain "best business practices" benefits from other countries, supporting diffusion growth.

A second illustration is the British wireless telecommunications conglomerate, Vodafone (www.vodafone.com). (See Figure 5.) This company has operations in many European countries other than its primary location in the United Kingdom, including France, Germany, Austria, Belgium, the Netherlands, Italy, Sweden, and Finland, among others.

But Vodafone also has direct investment relationships with other well-known wireless service operators throughout Europe, which creates the impetus for learning externalities and spillovers. Some of the ownership and investment relationships include Orange, which gives Vodafone an additional foothold in France, the Netherlands and Switzerland; and O2, which gives Vodafone coverage of Germany and Ireland that it may not get through its primary business activities. In addition, Vodafone is connected to other markets with portfolio investments in Verizon Wireless for coverage of the Americas, and T-Mobile primarily in European countries. The extent of the overlaps in coverage

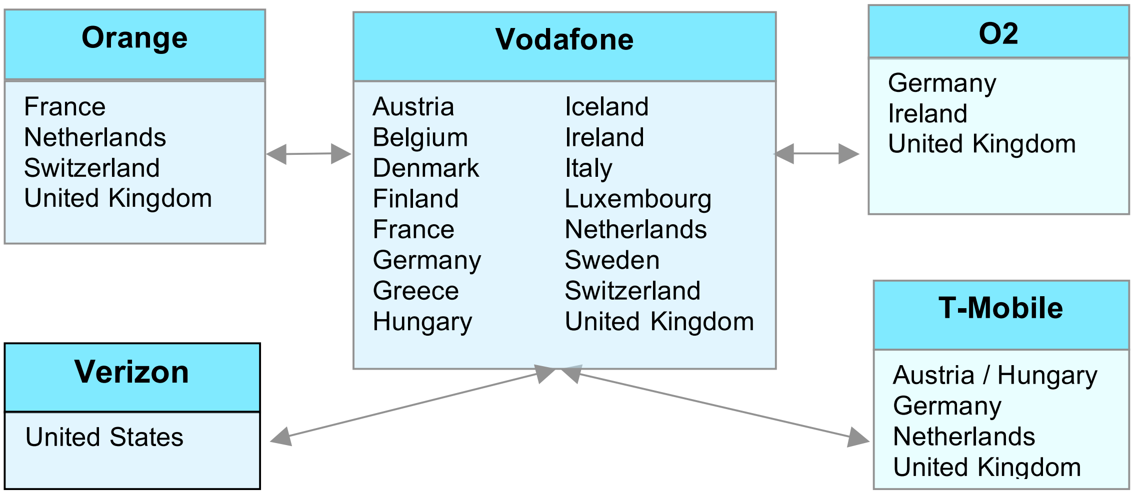

Figure 5. Selected Linkages among the Vodafone Family of Companies in Western Europe and North America

Note: We constructed the bilateral relationships between operators from information presented in Vodafone's "Global Footprint" presentation materials on its website, www.vodafone.com, which reports that Vodafone has interests in 26 countries, with partner networks in an additional 14 countries. Holdings in Asia Pacific are not depicted here, although they parallel those in the United States in size and financial significance for Vodafone.

across the many countries is further enhanced by Vodafone's "Partner Network" strategy, which enables it "to implement its global services in new territories, extend its brand reach into new markets, and create additional revenue without the need for equity investment" (Vodafone, 2005).

Table 10. Vodafone's International Partner Networks

Country	Operator	Country	Operator
Austria	A1	Hong Kong	SmarTone-Vodafone
Bahrain	MTC-Vodafone	Iceland	Og Vodaphone
Croatia	VIPnet	Kuwait	MTC-Vodafone
Cyprus	Cytamobile-Vodafone	Lithuania	Bite GSM
Denmark	TDC Mobil	Luxembourg	LUXGSM
Estonia	Radiolinja	Singapore	MI
Finland	Elisa Mobile	Slovenia	S.Mobil.Vodafone

Source: Vodafone (2005)

Based on the illustrations that we have offered, it is easy to see that there is an underlying set of corporate relationships that map onto the regional contagion links that we have identified. It is appropriate to suggest that the links may develop due to the business activities of wireless services providers, who are taking advantage of other underlying factors of the economy, the demographics of the population, and the readiness of the different cross-national marketplaces to adopt digital wireless phones.

Conclusion

We examined digital wireless phone adoption and diffusion growth, and analyzed subscriber and generational gaps among 43 countries in major regions of the world to understand the extent of the global digital divide. Our empirical methods included analysis of subscriber penetration and growth, econometric analysis of panel data models to explore country-specific drivers of diffusion growth, and the application of vector autoregression and variance decomposition approaches to measure regional contagion effects in global diffusion of digital wireless phones.

We found that faster growth of digital wireless phones occurs when a country has: a more well-developed telecommunications infrastructure, more competition in the wireless market, lower wireless network access costs, and fewer wireless technology standards. We also obtained a reading on cross-national influence of wireless diffusion. The countries we studied fell into three regional contagion groups: high, medium, and low. The Asia Pacific countries revealed a pattern of homogeneously high regional contagion links, while Western European countries were divided across the three groups.

Implications for Management and Policy Making

Our study aims to provide a better understanding of the presence and the intensity of the digital divides that exist in digital wireless phone technologies at country, regional, and global levels. The explanatory model that we proposed to understand drivers of adoption should also provide an actionable agenda for policy makers, especially in those countries that have low digital wireless phone subscription levels, to attempt to bridge the gaps. In addition, the fact that some countries can influence others in the technological diffusion process, particularly those that share regionally similar business, economic, and cultural traits, offers additional insights to understand the digital divide beyond what we have learned from the within-country factors.

Implications for Research

We also examined the extent to which regional contagion factors and geographical influences were able to explain the observed diffusion and digital divide patterns for digital wireless phone technologies. This regional contagion perspective should be applicable elsewhere to provide insights into the process of technological diffusion for different units of analysis and for different types of technologies. One of the examples that this theory can potentially explain is the diffusion of Wi-Fi across cities and towns. Another useful application is digital music, where the speed of diffusion of new hand-held electronics devices has been historically fast. A third potential study context is voice-over Internet protocol (VoIP), which will be diffusing rapidly in the coming years.

Our specification of regional contagion links via the modeling approach that we employ is unique in the study of technology adoption and diffusion. Our expectation is that this demonstration will encourage other IS researchers to explore the benefits associated with econometric methods that have been developed for the study of macroeconomic time series.

Limitations

There are a few limitations in our research. The lack of data prevents us from including additional countries, especially those in Latin America. In addition, there are time lags of two years for the digital wireless phone statistics published by the ITU. The 2004 publication provides data up to 2002 for some countries with missing data in several economies, so even this source is imperfect. We also recognize the difficulties that the international organizations have with ensuring data quality (similar to the concerns that have been expressed about data quality in the many studies on information technology investments and the productivity paradox). Within the limited quality of the data that we have obtained, there nevertheless are other opportunities for the study of reporting problems and data anomalies that we have not yet undertaken.

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