2-2014

Examining the growth of digital wireless phone technology: A take-off theory analysis

Angsana A. Techatassanasoontorn

Robert J. KAUFFMAN
Singapore Management University, rkauffman@smu.edu.sg

Citation

Techatassanasoontorn, Angsana A. and KAUFFMAN, Robert J.. Examining the growth of digital wireless phone technology: A take-off theory analysis. (2014). *Decision Support Systems*. 58, (1), 53-67.
Available at: https://ink.library.smu.edu.sg/sis_research/4861

Published in Decision Support Systems,
Volume 58, February 2014, Pages 53-67.
https://doi.org/10.1016/j.dss.2013.01.014

Accepted version

Examining the growth of digital wireless phone technology: A take-off theory analysis

Angsana A. Techatassanasoontorn [a,*], Robert J. Kauffman [b,1]

[a] Faculty of Business and Law, Auckland University of Technology, 42 Wakefield Street, Auckland 1142, New Zealand
[b] School of Information Systems, Singapore Management University, 80 Stamford Road, 178902 Singapore, Singapore

Keywords:
Survival analysis
Takeoff theory
Technology dominance theory
Technology life cycle
Technology standards
Wireless phones

ABSTRACT

The early phase of diffusion plays a critical role in determining information technology (IT) success in a market. *Takeoff*, the transition point from the introduction to the growth phase in the IT life cycle, is viewed as an acid test for whether a technology will succeed. We develop a theory to understand global takeoff for digital wireless phones that can be extended to other technologies with related characteristics. Drawing on technology dominance and product life cycle theories, we build a model that consists of standards, market competition, technology costs, and technology substitution to explain takeoff and subsequent market penetration growth. The data are from 41 developed and developing countries. The results suggest that the presence and effects of standards play an important role in driving takeoff and penetration growth. Familiarity with wireless phones and an installed base of analog phone technologies also explain faster takeoff times. Non-price factors are important drivers of penetration growth after takeoff as well. Our results have managerial and policy implications on innovative strategies, standards and competition policy settings for digital wireless phones.

> A slight incline, a relatively sharp rise, and then a fresh modification of the slope until the plateau is reached. This is also, in abridgment, the profile of every hill, its characteristic curve. This is the law which, if taken as a guide by the statistician and, in general, by the sociologist, would save them from many illusions.
> Gabriel Tarde, in *The Laws of Imitation*, Henry Holt, New York, 1903

1. Introduction

Information technology (IT) has to be widely diffused and used to yield social and economic benefits. The early diffusion phase of a technology plays an important role in determining its subsequent diffusion trajectory and eventual outcome in a market. For example, the fast growth of the VHS standard led it to defeat the Betamax standard and captured the market. The point of rapid growth is referred to as *takeoff* [21], the boundary between the introduction and growth phases of a technology.

Despite the successful global diffusion of various ITs (personal computers, wireless communication technologies, and the Internet), little systematic research has taken a careful look at the global takeoff of new ITs. The global IT diffusion literature in IS is broadly classified into two streams. The first stream studies diffusion patterns to get a reading on a range of factors that drive diffusion growth by fitting different diffusion models. These studies have assessed whether the influence of current adopters, other external factors, or a mix of both drives diffusion [39]. The second stream focuses on establishing a set of factors that drive the overall diffusion process of a technology without reference to any specific diffusion phase [8]. A fuller understanding of the factors that are important in different diffusion periods is still needed. Since successful takeoff determines whether a technology will widely diffuse, deeper theoretical insights into the process are appropriate for this also.

Drawing on technology dominance and product life cycle theories, we develop a new theory for the global takeoff of a new technology. Some researchers use the labels *technology dominance theory* and *product life cycle theory* interchangeably to refer to the evolution of industry dynamics of firm entry, firm exit, and market competition [34,35]. In the past several years, a complementary literature [2,9,47,50] has used the label *product life cycle theory* to develop a related body of knowledge on product life cycles from a user demand and adoption perspective. It identifies four critical phases in a product life cycle: *introduction*, *growth*, *maturity*, and *decline*. The product life cycle literature, in addition to inclusion of the effects of industry dynamics or supply-side factors, examines institutional and contextual factor influences on product adoption during different life cycle stages. We use technology dominance theory for an explanation of the evolution of technological change from an industry perspective, and product life cycle theory to refer to the theory and related studies that offer a complementary explanation to understand technological change through user adoption.

Our aim is to develop a theory to explain takeoff and growth of network-based innovations in general and digital wireless phones in particular. We chose digital wireless phones for two reasons. First,

---

[*] Corresponding author. Tel.: +64 9 921 9235.
E-mail addresses: angsana@aut.ac.nz (A.A. Techatassanasoontorn), rkauffman@smu.edu.sg (R.J. Kauffman).
[1] Tel.: +65 6828 0929.

wireless phones are widely regarded in the international community as a promising platform to increase economic growth and shape social progress, particularly for developing countries. Second, from the industry and innovation perspectives, wireless phone value networks have become increasingly complex with intense competition, requiring firms to develop effective strategies to grow their revenues.

We emphasize the extension of the *theoretical logic*, *explanatory accuracy* and *generalizability* as key qualities for strong explanatory theory development [25]. We combine a supply explanation from technology dominance theory and a demand explanation from product life cycle theory to offer a more accurate theoretical logic for takeoff and growth of IT innovations. To further enhance our explanation of the logic of successful innovation and diffusion for a complex technological system, we view an industry as "consisting not only of the set of firms producing similar or substitute products … but also many other public and private sector actors who perform critical roles in developing and commercializing a new technology" [52, pp. 367–368]. In the wireless phone industry, institutions shape industry dynamics through standards and competition policies. We aimed to generalize our theory by including both developed and developing countries in our sample.

Understanding the success of global network-based innovations (e.g., cloud computing, social media, video games, wireless phones) is at the nexus of IS and operations management research. The value networks for these innovations involve a large number of firms with a set of complex relationships. Their innovation and production activities span national and firm boundaries too. For example, key players in a wireless phone value network include operators, phone manufacturers, content and technology providers, component suppliers, infrastructure suppliers, and handset manufacturers, among others. There were tens of thousands of firms in the Japanese wireless phone industry alone [17]. For instance, the Motorola V3 RAZR phone has 640 parts from various companies in multiple Asian countries and the U.S. [10]. Establishing an understanding of global takeoff and further growth of these innovations is important for firms in a value network to develop short and long-term capacity planning, partnerships, and global coordination of supply chain to appropriate value from their innovations.

Our research questions are: (1) Can theory aid in understanding global takeoff of digital wireless phones? (2) What factors appear to be salient in driving global takeoff? (3) What are the drivers of penetration growth during the growth phase of the digital wireless phone technology life cycle?

Our theory development begins with orienting explanations from *technology dominance theory* [3] and *product life cycle theory* [21] for the takeoff and subsequent growth of a technology. The former offers an understanding of the industry and supply-side factors brought about by technological change and how they explain takeoff and growth. The latter highlights user adoption behavior and its antecedents in different product life cycle stages. Then, we develop a theoretical model that consists of salient factors for wireless phone diffusion to explain takeoff and penetration growth in the growth phase. They include standards, market competition, technology cost, and technology substitutes. We also consider the role of country-specific effects that influence technology adoption [4]. The four country contextual variables are wealth, wealth distribution, region, and education. (See Fig. 1 for illustrative examples of slow and fast takeoff of digital wireless phones in selected developed and developing countries.)

To empirically evaluate the model, we use proportional hazard regression analysis to test the factors that drive takeoff times.[2] We conducted panel data analysis to test factors that drive further penetration growth from the takeoff to the maturity phases. The data are drawn from 41 developed and developing countries. The results suggest that standards are the key driver of takeoff and further penetration growth. Countries that have high analog wireless phone penetration will experience faster takeoff than those with low penetration. Market competition also explains high penetration growth after takeoff.

2. Theory

To understand takeoff and diffusion growth in a network-based industry, we focus on standards and innovation. Technology dominance and product life cycle theories suggest the role of dominant designs or standards, network effects, firm strategic actions and industry structure in the growth of the IT industry.

2.1. Technology dominance theory

Technology dominance theory examines the interaction between the characteristics of technology and industry dynamics, and the implications for technology adoption from initiation to obsolescence [5]. Research in this area offers implications for strategic decisions related to resource allocation, and forecasts for technology design, production, and marketing. It is a *process theory* that explains activities surrounding technological change via market structure, including firm entry, firm exit and competition, and technological innovation through product and process improvement. Market competition, quality improvement, and technology cost also may explain the uptick in demand that leads to takeoff.

The theory argues that technological changes shape the trajectories of industry attractiveness, structures, and its level of competition.[3] Technological change is an evolutionary process though. Firms invest in product and process innovations to survive and maintain competitiveness. *Product innovation* is investment to improve quality and performance of a technology (cheaper processors, better voice recognition or faster data speeds). *Process innovation* is investment to bring the production cost of technology down (using robots to increase order fulfillment speed, Dell's made-to-order computers, or improved process technology to manufacture semiconductors). The evolutionary process fits the innovation cycles in wireless communications; they are built around generations of dominant designs of wireless standards.

Technological discontinuities trigger introduction of variants of a new technology and intense competition for dominance. Product innovation dominates process innovation during this period. Before the emergence of a dominant design, the rivalry between alternative technological standards creates uncertainty. However, the realization of a dominant design tends to create stronger entry barriers that slow down firm entry and increase exit by firms that lack knowledge, economies of scale in production, or strong inter-firm relationships to compete. Building a dominant design also leads to higher investment in process innovations and incremental technological progress through smaller investments in product innovations. To expand their market, firms increase investment in process innovation while reducing product innovation. This leads to lower production costs and falling technology prices. When the market matures, the number of firms stabilizes, and product and process innovation begins to slow down.

The dominant design explanation and the product and process innovation view do not apply very well to some products, including IT innovations. In the camera industry between 1955 and 1974, a dominant design did not emerge in an environment of heterogeneous

---

[2] Previous IS studies used variants of event history methods to study IT outsourcing vendor–client firm relationships [23], album popularity on the Internet [6], user search engine visits [49], vertical integration on IT adoption in firms [14], adoption of electronic banking networks [31], and Internet firm failures [30]. A fuller review of event history methods and other relevant methods and literature for IS and e-commerce research is available for the interested reader [32].

[3] The management literature uses the term *dominant designs* to explain technological change and competition. By contrast, economics focuses on the importance of *technology dominance* by referring to *standards* in network industry competition.

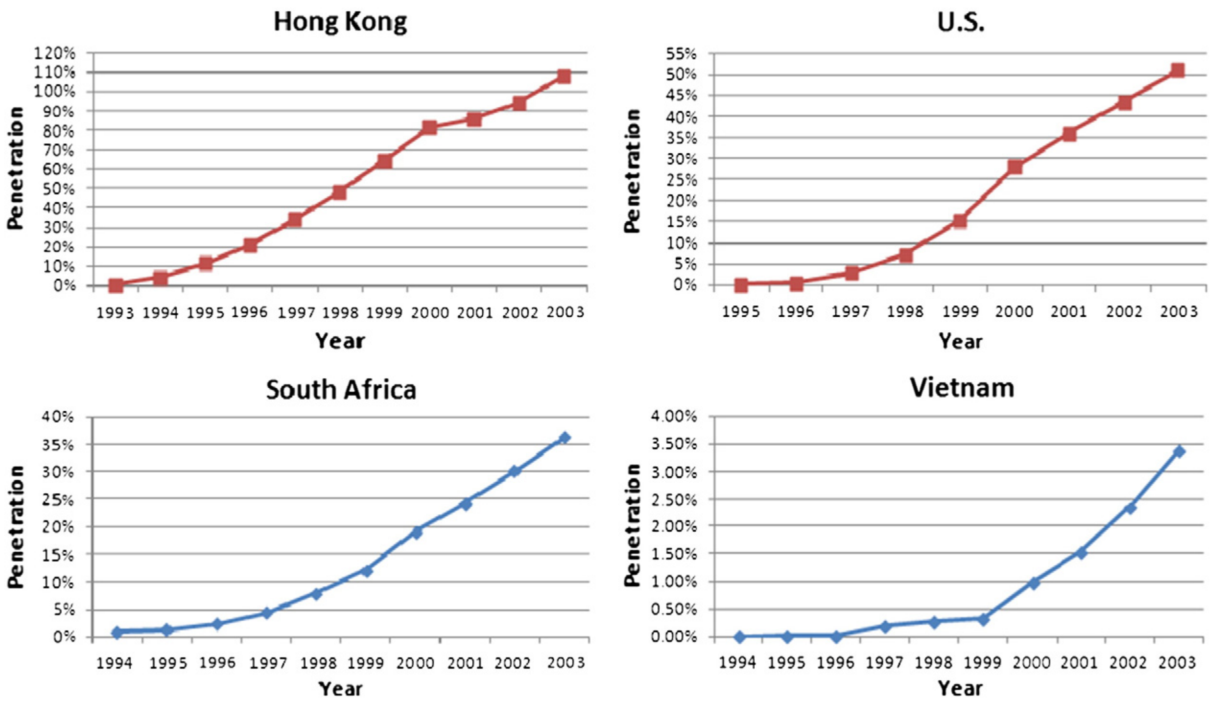


Fig. 1. Illustrations of digital wireless phone takeoff and penetration in selected countries.

demand [55]. Similarly, there was no evidence of a dominant design during 1981 to 1999 for wireless phone handsets [16]. Apparently market structure and innovation don't have much to do with the emergence of dominant designs [34]. Instead, ROI is largely influenced by firm capabilities and firm size.

Technology dominance research, with its focus on the supply explanation (involving firm entry, exit and capabilities), has not given attention to the role of consumers in shaping technological change. In a study of 46 new products ranging from tires and computers to windshield wipers and zippers, technological characteristics and consumer preferences affect industry evolution [35], but there has not been systematic evidence to support this claim. Another study of consumer demand and preferences showed that they explain technological progress [1]. The effects of consumer valuation of technology arise through two components: functionality requirements and willingness-to-pay. An additional period of technology evolution is often observed in digital and information-based industries. This period shows stable prices and increasing performance, which contrasts with the prediction of the decline in innovations. Competitive pressure is the main force that leads firms to improve performance without increasing price.

The change from first to second-generation digital technology was critical for evolution in wireless communications. The Advanced Mobile Phone System (AMPS) standard originated in North America and was the dominant 1G analog standard, with 85 adopting countries and 80% of worldwide subscribers in 1998 [19]. The U.S. observed a rivalry among three 2G digital standards.[4] The competition created uncertainty in the U.S. Firms preferred to adopt a wait-and-see strategy for fear of locking into a standard that might not eventually have succeeded as a dominant standard. On the other hand, the mandate from the European Union for its members to adopt GSM and the open standard setting process that includes both domestic and foreign firms helped GSM to become a dominant global digital standard, with 110 adopting countries and 62% of worldwide subscribers in 1998 [19].

2.2. Product life cycle theory

A *product life cycle theory* classifies technology penetration or sales growth over time into four phases: *introduction*, *growth*, *maturity*, and *decline* [5]. Introduction has slow sales growth, followed by rapid sales growth in the growth period. Sales level off when the technology reaches maturity and drop off in the decline period. The evolution of technology growth is an S-shaped curve.

Although we must understand the overall diffusion of products, product life cycle research pays more attention to the takeoff of new products.[5] Agarwal and Bayus [2, p. 1024] argued that "understanding the timing and causes of … takeoff is critically important for industry analysts and managers because they have serious short and long-term resource implications for research and development, product development, marketing, and manufacturing." Product life cycle research suggests that time-to-takeoff varies by types of innovations, technology generations and countries [9,50]. For example, we know from prior research that new generations of a product experienced faster takeoff, and older generation products needed to overcome a stronger novelty effect [47].

The mean time-to-takeoff seems to be longer for developing compared to developed countries for products associated with entertainment or information use (e.g., DVD players, wireless phones), but is faster for products designed to make everyday life more convenient (e.g., dishwashers, dryers) [9]. Takeoff also is influenced by competition, evolution of technology development, and the cost of technology. The timing may be related to market infrastructure, including distribution channels, methods of payment, and complementary products and services, and how they evolve. In the case of digital wireless phone technology, data services on wireless phones need operating systems, applications, and contents that are designed for wireless phones [40].

---

[4] These three standards are the Digital-Advanced Mobile Phone Service (D-AMPS) standard, the Code Division Multiple Access standard (IS95 CDMA) and the Global System for Mobile Communications (GSM) standard.

[5] The concept of *takeoff* is related to the idea of a *tipping point*. It triggers change from a slower to a faster pace of adoption, and occurs when a critical mass of users adopts an innovation. A *critical mass* of adopters makes adoption self-sustaining in the marketplace. It is relevant to the growth of interactive systems, in which adopters communicate, interact, and exchange information.

Other research has shown that price reductions drive takeoff of consumer electronics products [21]. Golder and Tellis [21] found that average time-to-takeoff of 31 new products was six years, with a 1.7% penetration at takeoff time across all products. A study of thirty consumer and industrial innovations (e.g., automobiles, dishwashers, microcomputers) in the U.S. between 1849 and 1983 found that increases in supply and demand lead to market takeoff, and that sales takeoff occurs quicker in a highly competitive market [2]. Also competition for demand through non-price factors representing actual and perceived product improvements dominates the influence of price on sales takeoff times. Still other research examined takeoff for ten consumer durables (e.g., CD players, dishwashers) in sixteen Western European countries, emphasizing economic, cultural, and product variables [50]. Sales of most new products again exhibited takeoff after an average of six years.

Network effects explain diffusion of IT products and services, such as software, video games and modems. Network effects refer to the increasing benefits as additional users adopt an interactive technology.[6] For example, The U.S. and South Korea experienced fourteen years of time-to-takeoff for fax machines, twice as long as consumer durable products, which have exhibited an average time-to-takeoff of about seven years [38]. The level of network effects in the wireless phone industry is known to be high also.

Overall, the product life cycle literature offers interesting explanations related to the takeoff of new innovations. There are still limitations and gaps though. First, there is a lack of empirical research that systematically examines takeoff of new technologies in the IS literature. Understanding of factors, such as standards and related technologies that are important to IS practitioners, policy-makers, and researchers, is needed. Second, there is a lack of validated measures to determine when takeoff occurs. Researchers have developed specific heuristic measures that may not be widely applicable though [50].

Third, though diffusion of many new technologies is global, most of the existing studies have focused on the U.S. [2] and Western Europe [50]. Because developing countries have different economic conditions, infrastructure and human capital development, theories developed in the context of developed countries need to be extended and tested for developing countries. In addition, studies seeking to establish generalizability beyond the original setting offer opportunities for important scientific advances in research and to increase the usefulness of theory for practice. We address these limitations. First, unlike some studies that used a heuristic approach to identify takeoff, we use a validated analytical method to identify phases and takeoff times in the digital wireless phone life cycle. Second, we consider variables such as costs and standards that provide insights for IS managers and policy-makers on the dynamics of takeoff. Third, we include developed and developing countries in our sample. This should enhance our understanding of drivers that are important to takeoff and offer stronger policy and managerial insights for developed and developing countries.

3. Theory and hypotheses

We next develop a model that treats issues of technology standards, market competition, technology costs and substitutes, and context and country-specific factors to explain digital wireless phone growth. We focus on three variables to explain the global takeoff of digital wireless phones: the degree of market competition, relevant technology costs, and the presence of technology substitutes. We use the dependent variable, time-to-takeoff, measured by the duration from introduction to takeoff. We also examine another related dependent variable – the extent of penetration growth during the growth phase – as a means to provide deeper insights on explanatory factors at different stages of the technology life cycle. Since our goal is to develop a model of digital wireless phones, we need to include domain-specific constructs to deepen our understanding of takeoff and digital wireless phone growth.

In the wireless phone industry, institutional factors also play a key role in successful development and diffusion [26]. Governments, in particular, are instrumental in the development of standards, industrial policy, liberalization and licensing policies in the wireless phone industry [18]. For example, the South Korean government played an active role during the early development and commercialization of digital wireless phone services through the mandate of the CDMA standard, additional licensing to increase competition, and R&D funding [56]. We will focus on the *number of standards*, to gauge the diffusion speed of wireless phones [36,44].

Innovation diffusion theory argues that uncertainty delays adoption.[7] Since a lack of standards creates market risks and uncertainty, it may explain how adoption works. According to product life cycle theory, competition and technology costs are important drivers for takeoff. Firm entry and competition generate market changes, including capacity expansion, product variety, and price declines. These regularities are observed across IT innovations, including mainframes, PCs, and wireless phones. Thus, competition and prices may explain the takeoff of digital wireless phones too. We include technology substitutes as another explanatory variable for takeoff. They are related to *technology clusters*, elements of technology that are perceived as being closely interrelated. Past research tended to investigate each innovation as if it were independent from other innovations. These studies oversimplified the reality in which several interdependent innovations are diffusing together. As a result, the diffusion patterns of these technologies are interdependent and the direction of influence depends on their complementarities and substitutability.

Global diffusion of a new IT is complex due to the disparity in the countries' levels of development. Many countries have different local preconditions (infrastructure, institutions, culture) that influence adoption. An integrated global perspective can explain digital wireless phone takeoff and growth across countries. We identified appropriate strategies to address the local country conditions from previous international studies in the IS literature.[8] Table 1 shows the contexts used to study cross-country differences.

---

[6] We use the term *network effects* to indicate the additional value that arises from the usage of a product or service by an installed base of users, and which is subject to increases or decreases when the installed basis rises or falls. *Network externalities*, by contrast, refer to network effects that producers in the market are not able to internalize in their firms.

[7] Technology adoption has also been studied from the economics perspective. Hoppe [28] provides a useful orienting perspective for interested readers to understand the general structure of the related economics literature in this area by distinguishing among theoretical models that characterize *non-strategic and strategic firm interactions* in the product market versus *certain and uncertain arrival and value of the new technology* of interest. The simplest versions of these models involve non-strategic adoption with certain arrival and value. An example is that firm size effects on adoption with no strategic interactions between firms may affect the payoffs. Other settings may not involve strategic interactions, but may include uncertain arrival and value for the technology. Still other settings may have strategic interactions, which may be affected by changes in demand, firm competition or technology advances. Our setting involves no direct strategic interactions or between-country rivalry, however, the behavior that we are observing is characterized by uncertainty related to the arrival and value of digital wireless phones.

[8] From a theory development standpoint, *generalizability* about a phenomenon is viewed as the core of a theory. *International generalizability* is one of the important criteria to assess the value of a global study of IT [43]. Local diversity in understanding the global application of IT is important too [4]. In less developed countries, the environment presents greater obstacles to IT adoption and diffusion. It is less likely that IT is used and its value is appropriated in the same manner across countries in the world. Country diversity, including economic development, cultural differences, infrastructure, and institutional actions, have been examined in previous global IT studies.

Table 1
Literature on international development and IT with research contexts.

Focus	Study	Context	Countries	Approaches
Differences	Zhu et al. [58]	E-business adoption	10 developed, developing	Sample analysis
Culture	Srite and Karahanna [46]	PDA adoption	30 countries	Culture aspects
	Walsham [54]	Software team	India, Jamaica, U.S.	Case studies
IT infra-structure	Zhu et al. [59]	Internet adoption	10 developed, developing	ICT penetration as control variable
Institutional support	Montealegre [41]	Internet adoption	Chile, Costa Rica, Ecuador, Peru	Case studies
	Silva and Figueroa [45]	IT adoption	Chile	Case study

International IT innovation research in IS suggests that international effects [57] and local diversity matter [4]. Different socio-economic conditions of developed and developing countries in the areas of infrastructure, education, culture, and institutions are critical to explain differences in IT diffusion among different countries. Income and education are among the key socio-economic drivers of wireless phone adoption [29]. We will examine four variables: *wealth*, *wealth distribution*, *education*, and *regions*. Consistent with previous IS research [11,57], we also explore the international differences through sub-sample analysis of developed and developing countries.

Diffusion research suggests that wealth shows adopters' ability to pay, permitting them to evaluate a technology for adoption [48]. Wealthier individuals can afford to take risks of adopting a new technology early [50] because new technology costs tend to be high when it is initially introduced in a market. (Consider this — a wireless phone in 1983 cost $3,000!) Wealthier people often are the only ones who are able to afford a new technology. How wealth is distributed in a country, thus, has an important effect on diffusion and takeoff. If wealth is concentrated, many people may be unable to afford to adopt, and diffusion will be slow. This will delay takeoff — or it may never occur. Tellis et al. [50] found support for this in the cross-country diffusion of more than 100 new products. Diffusion of innovation theory and related empirical studies identified education, and other demographic characteristics, as influential in IT adoption. Early adopters before takeoff of a new IT tend to be better educated.

IT innovation and product takeoff research suggests that culture may explain differences in IT diffusion and takeoff times across countries. There is evidence that takeoff seems to be higher in countries with cultures that have lower uncertainty avoidance and place higher value on achievement and industriousness [50], but others have objected to this simplistic explanation [42].

Global IT adoption research findings suggest different patterns of IT usage by world regions. Japan, South Korea and other Asian countries, for example, enjoy advanced multimedia data applications on wireless phones. Users in developing countries in Africa rely on wireless phones for basic economic needs, including seeking employment, access to healthcare, and finding markets for small businesses. Others have reported differences in product and IT diffusion between developed and developing countries [8]. For example, Chandrasekaran and Tellis [9] found that the mean time-to-takeoff of several technology products varied for developed and developing nations. Thus, we expect regional differences in our research.

We use *cultural clusters* to evaluate the influence of different cultures on digital wireless phone takeoff and growth. Countries located in the same clusters share similar culture because of geographic proximity, common language, ethnicity and history. We apply a broad classification (e.g., Africa, Asia, America and Europe), and a finer classification of cultural clusters (e.g., Asia Pacific, Mideast, etc.). Fig. 2 shows our model of wireless phone takeoff and growth. We now discuss the main hypotheses.

3.1. Standards

Competing standards slow down product growth and create uncertain outcomes [47]. With two competing standards, there are a few possible outcomes. One may take off and gain wide acceptance while the other fails. The worst case is that, due to the uncertainties about one standard over another, neither takes off, leading to unsuccessful diffusion. A good example is Beta and VHS in the videotape format. The lack of a single standard slowed the rate of adoption of VCRs until the VHS format got an edge in the market. Funk [16] analyzed 1G, 2G, and 3G wireless phone technologies and found that the choice of the single analog AMPS standard by the U.S. and the single 2G digital GSM standard by the European Union were important to create large-scale adoption. Thus, a lack of standards or the presence of multiple standards slows down diffusion and delays the takeoff. We propose:

- **H1a (The single standard for takeoff hypothesis)**. *Countries with a single standard experience faster takeoff of digital wireless phones.*

- **H1b (The single standard for penetration growth hypothesis)**. *Countries with a single standard experience higher penetration growth of digital wireless phones after takeoff.*

3.2. Market competition

The technology dominance and product life cycle theories suggest that competition can increase market demand through mechanisms related to prices and non-price factors (e.g., product quality and features). For products, competition exerts pressure for firms to improve their technology, expand product offerings, and increase product differentiation. Competition also puts pressure on firms to reduce prices, which leads to increases in sales. For some IT products and services (PCs and software), the market is not subject to regulation. Thus, market processes, firm capabilities, and anticipated demand are the mechanisms underlying firm entry and competition. However, some network technologies (the Internet, fixed and wireless phones) are often subject to regulation. To manage the radio frequency spectrum, countries offer a limited number of wireless phone licenses, and operators have to compete for a license before they can start providing services to subscribers. Several countries award one available wireless phone license to the incumbent fixed-phone line operator while the rest go to market entrants.

The number of operators in digital wireless phone markets tends to be small. In 2004, Australia had four operators, China two, and Germany four, for example. Nevertheless, the evidence suggests that competition in wireless phone markets is likely to increase demand and speed up diffusion [27]. As early as 1995, when the digital wireless phone industry was just establishing itself, competition in the wireless phone market created several benefits, including price reductions, increased market growth, and increased applications. Agarwal and Bayus [2] found that higher competition led to faster takeoff of products, including analog wireless phone technology in the U.S. So we also propose:

- **H2a (The telecom market for competition hypothesis)**. *Countries with higher telecom market competition experience faster takeoff of digital wireless phones.*

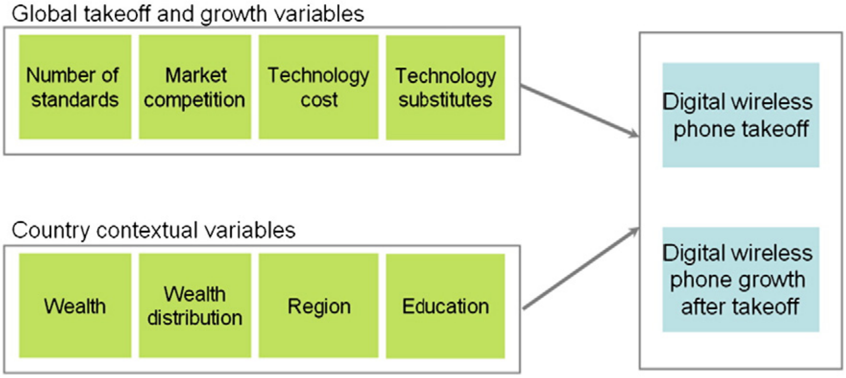


Fig. 2. A model of digital wireless phone takeoff and growth.

- **H2b (The telecom market competition for penetration growth hypothesis)**. *Countries with higher telecom market competition have higher penetration growth of digital wireless phones after takeoff.*

3.3. Technology costs

Technology costs are a barrier to technology adoption. Anecdotal evidence from the analog wireless phone market suggests that falling prices of handsets increased market growth in the late 1980s [16]. Other studies that examine takeoff of new innovations also found that falling prices can trigger increased demand and subsequently lead to takeoff [2,47]. This is because prices tend to be very high when an innovation is first introduced [21]. Over time, prices decline due to competition and investment in process innovations though. Takeoff occurs when prices drop so innovations become more affordable. Thus, we assert:

- **H3a (The technology use cost for takeoff hypothesis)**. *Countries with lower costs to use digital wireless phones experience faster takeoff of digital wireless phones.*

- **H3b (The technology use cost for penetration growth hypothesis)**. *Countries with lower costs to use digital wireless phones experience higher penetration growth of digital wireless phones after takeoff.*

3.4. Technology substitutes

Economic theory suggests that consumer willingness-to-pay depends on the availability and prices of substitute products or services. With rapidly advancing technology, technology substitution occurs for many different technological products. Two products are *substitutes* if a price increase for one leads to an increase in sales of the other. Analog and digital wireless phone technologies work this way. Although digital technology offers significant improvements over analog technology, including increased voice quality and enhanced security, handset and service prices of digital technology are higher. Individuals compare technology prices and performance when they make adoption decisions.

Digital wireless phone adopters fall into two groups: analog wireless phone users who are considering upgrading, and others who haven't used wireless phones. *Referent point theory* posits that individuals use their most recent purchase as a reference point for future purchases in the same product category. For example, an owner of an older generation PC is more likely to use that machine to compare the performance and prices of newer PCs [33]. Thus, we expect those who use analog wireless phones to use their experience with analog technology as a reference point when evaluating the performance and prices of new digital wireless phones. The takeoff of digital wireless phones may be delayed if many decide to adopt analog technology during the introduction of digital technology. Thus, we propose:

- **H4a (The analog substitution effects for takeoff hypothesis)**. *Countries with weak substitution effects from analog technology are likely to experience faster takeoff of digital wireless phones.*

- **H4b (The analog technology substitution effects for penetration growth hypothesis)**. *Countries with weak analog substitution effects will have higher penetration growth for digital wireless phones after takeoff.*

4. Empirical models

We examine two outcomes: *time-to-takeoff* and the *extent of penetration growth after takeoff*.

4.1. An event history model

Since takeoff is a time-dependent event, event history models are useful to test the influence of related factors on time-to-takeoff. We use *proportional hazard regression*. Parametric models are less appropriate because we have no information on the form of the underlying distribution of the baseline hazard or likelihood of an event at some point in time. A particular distribution will not bias our results either.[9]

Time-to-takeoff can be modeled as a function of a baseline hazard and explanatory variables. The hazard function of country i is $h_i(t) = h_0(t)\exp(\beta X_{it})$. Here $h_0(t)$ is the baseline hazard, X_{it} is a vector of explanatory variables for country i at time t, and β is a vector of parameters. The proportional hazards model assumes the hazard ratio of two countries is constant over time.

4.2. Panel data model

We use a panel data model to examine factors that influence penetration growth after takeoff. Previous research suggests that the growth phase of most products often lasts several years [22]. Our panel data consist of several observations for each country. We use a random-effects specification to test the explanatory factors for penetration growth during the growth phase of the digital wireless phone life cycle: $y_{it} = \alpha + \beta X_{it} + u_i + \varepsilon_{it}$, where $i = 1, \ldots, I$ denotes countries and $t = 1, \ldots, T$ denotes years. The dependent variable, y, is the annual

---

[9] This is attractive to let the data communicate information about the setting to an analyst. The *hazard function*, or likelihood of an event of interest to be observed, can be represented through a proportional difference as the variable z changes over time t, via $h_z(t) = g(z)h_0(t)$, in which $h_0(t)$ is the *baseline hazard function*. The *proportionality constant* $g(z)$ is a function of z but not time t.

Table 2
Summary statistics of key variables.

Variable	Measure	Mean	Std. dev.
Takeoff	Duration from commercialization to takeoff	2.32 years	0.82 years
Penetration growth	Penetration growth during the growth phase	213%	108%
Standards	Number of digital wireless phone standards	1.17	0.45
Market competition	Number of digital wireless phone operators	2.73	1.45
Technology cost	PPP-adjusted cost of 60-minute peak-rate local calls	25.26	17.84
Technology substitutes	Extent of analog wireless phone penetration	1.66%	3.29%

penetration growth of digital wireless phones, α is an intercept, the vector X contains explanatory variables, and the βs are the estimated coefficients. There are two unobserved components: u_i reflects country heterogeneity, and ε_{it} is an error term that varies across time, and may vary across groups of countries. The model treats differences through u_i as normally-distributed random variables.[10] We can extrapolate the finding to other countries outside the sample.[11]

5. Data

We now consider the definitions and measures that we will use in this empirical research for the key variables in the model. The first dependent variable is duration from commercialization to takeoff in the digital wireless phone life cycle. The second is penetration growth during the growth phase.[12] To operationalize our dependent variables and determine when takeoff occurs, we define three events to mark the boundaries of the beginning of the first three phases in the life cycle. Commercialization begins when digital wireless phones are first introduced to users in a market. The second event that identifies the end of the introduction phase and the beginning of the growth phase is takeoff, the first dramatic and sustained increase in penetration. The third event that identifies the end of the growth phase and the beginning of the maturity phase is slowdown, the period when sales growth slows down or levels off.

Our commercialization measure is the first year in which digital wireless phone services become available. Measures of takeoff and slowdown required proxy variables. The rapid increase in penetration associated with takeoff and the leveling off of sales associated with slowdown can be problematic to recognize.

Previous studies proposed three methods to measure takeoff: heuristic, diffusion model estimation, and discriminant approaches. Tellis et al. [50] operationalized takeoff as the first year a new product's growth rate relative to the prior year crosses a predefined threshold based on penetration levels. The pre-specified takeoff threshold is simple and works across many products and countries, but it lacks theoretical or empirical support. The diffusion model estimation approach derives a takeoff point from a specific diffusion model such as the Bass model [38]. Thus, this approach makes a strong assumption about the patterns of diffusion and may bias the estimation of takeoff time. We chose the discriminant approach [2] because this method is rigorous and doesn't require that all technologies need to go through all four life cycle phases. We first used a visual analysis to classify time-series that belong to certain phases. We classified the remaining data in either of two adjacent phases as in-between phases. They include the in-between introduction and growth phase, the in-between growth and maturity phase, and the in-between maturity and decline phase.[13] (See Table 2 for the regressors.)

Standards are measured by the number of digital wireless phone standards in a country. Market competition measures the number of digital wireless phone operators. Technology costs are measured by purchasing power parity (PPP)-adjusted sixty-minute peak-rate local calls. Substitution is measured by analog wireless phone penetration. Country contextual variables are wealth, wealth distribution, regions, and education. Wealth is measured by PPP-adjusted GDP per capita in international dollars, and wealth distribution by the GINI index, ranging from 0 to 100. A greater value of the GINI index reflects a higher level of wealth inequality. Countries are in four geographical regions: Africa, Asia, Europe, and America. Education is measured by the 2004–2005 World Economic Forum's advanced Human Capital Index, which captures enrollment, education system quality, and training. (See Appendix A.)

---

[10] The reason for our selection of a *random effects model* for estimation is because it is a better choice when its primary assumptions are met, and because it produces efficient estimates. In our case, we do not assume country-level fixed effects. The model measures the difference between the average level of adoption in a country relative to the average level of adoption in the world. There is also an implied assumption that gives the estimation method its name, which is a little more difficult to defend: that the countries in our sample were chosen randomly from among all of the possible observations in the world. This is untrue in most studies of international development involving technology and other influential factors of interest at the national level, of course, although the fixed effects assumption is often used.

[11] The country-specific effects must be orthogonal to, or uncorrelated with the explanatory variables though. We will test this assumption. The usual approach is to run a random effects model and a fixed effects model, and then perform a Durbin–Wu–Hausman specification test, to determine whether one specification is better than another, in terms of the consistency of the estimators with the smallest asymptotic variance. Similar to the survival model of takeoff, the panel data model allows countries to have a different number of data points depending on the time a country is in the growth phase.

[12] Prior research classified the technology life cycle into four phases: introduction, growth, maturity, and decline [5,22].

[13] We classify the penetration growth time-series into the introduction, growth, and maturity phases with the following seven algorithm steps. (1) We plot the growth data by time, and visually examined the data points that clearly fall into the growth patterns of one of the three phases. Growth tends to be slow during the introduction phase. Growth increases dramatically in the growth phase and levels off in the maturity phase. The remaining observations are then classified into two groups: the in-between introduction and growth phase group, and the in-between growth and maturity phase group. (2) We next standardize the growth data to eliminate heterogeneity across countries by dividing each observation by the mean value of penetration growth for the growth phase. (3) We then use discriminant analysis to classify observations in the in-between phases into the appropriate life-cycle phases. Let $x_1, \ldots, x_t$ represent the observations in the in-between the introduction and growth phases. We seek to establish an optimal year j such that $x_1,\ldots, x_j$ are classified in the introduction phase and x_{j+1}, x_{j+2}, …, x_t are classified in the growth phase. The $x_1,\ldots, x_j$ should resemble the observations that are initially classified in the introduction phase more than those initially classified in the growth phase. Also, $x_{j+1}, x_{j+2},\ldots, x_t$ should be more similar to others initially classified in the growth phase than in the introduction phase. We use the means of penetration growth as our criterion to determine similarity. (4) Next, let $\widehat{\mu}_1$ and $\widehat{\mu}_2$ be the means of penetration growth of the standardized observations classified in the introduction and growth phases. We choose values $j=1, \ldots, t$ that partition the in-between observations into two groups and calculate the mean penetration growth of those two groups: $d_1(j) = \frac{\sum_{i=1}^{j} x_i}{j}$, and $d_2(j) = \frac{\sum_{i=j+1}^{t} x_i}{t-j}$. The choice of j needs to satisfy the similarity criterion, such that $|d_1(j) - \widehat{\mu}_1| \le \left|\frac{\widehat{\mu}_1 - \widehat{\mu}_2}{2}\right|$ and $|d_2(j) - \widehat{\mu}_2| \le \left|\frac{\widehat{\mu}_1 - \widehat{\mu}_2}{2}\right|$. (5) If no values satisfy this criterion, then we classify all observations in the introduction phase if $|d_1(t) - \widehat{\mu}_1| < |d_1(t) - \widehat{\mu}_2|$, and in the growth phase otherwise. (6) If there were multiple values of j that satisfy the similarity criterion, then we select j to maximize the difference between the mean penetration growth of the two phases, $|d_1(j) - d_2(j)|$. (7) We repeat Steps 3 to 6 to similarly classify observations in the in-between growth and maturity phases.

6. Results

We next present two sets of results based on proportional hazard regression and panel data analysis.

6.1. Proportional hazard regression results for factors influencing time-to-takeoff

The results for factors that influence time-to-takeoff for digital wireless phones with network effects [7,15,24], measured by digital wireless phone penetration (*DIGITAL*) are shown below. (See Tables 3 and 4, and Appendix B for the proportional hazard assumption test.)

The network effects (*DIGITAL*) are not significant ($p = 0.33$). We conducted additional analysis based on a finer classification of cultural clusters.[14] (See Table 5.) The results are comparable with those for four regions (Africa, Asia, Europe, and America). The χ^2 (5 d.f.) of the likelihood ratio test between the model with four regions and the model with nine is 8.26 ($p = 0.14$), indicating no difference between the two models. Thus, we use the results from Table 3 to report our findings.

6.1.1. Estimated parameters

We tested the influence of standards (*STD*), market competition (*COMP*), technology costs (*COST*), and technology substitutes (*ANALOG*) on time-to-takeoff. The control variables are wealth (*GDP*), wealth distribution (*GINI*), regions (*Africa*, *Asia*, *Europe*), and education (*EDU*). All have correlation coefficients less than 0.7, except *ANALOG* and *GDP* at 0.71. So we dropped *GDP* to avoid unstable coefficient estimates.[15] The model was significant (log-likelihood = 29.93; $p < .01$). The number of standards (*STD*) was significant too ($p < .01$), with a coefficient of −1.44 and a hazard ratio of 0.24: so an additional standard in a country decreased the hazard rate to reach takeoff by 76%. Thus, the Single Standard for Takeoff Hypothesis (H1a) is supported with our data.

Technology substitution based on analog wireless phone penetration (*ANALOG*) also was significant ($p < .01$) but with a near-zero coefficient and a hazard ratio near to 1. So analog wireless phone penetration appears to have had little impact on the hazard rate to reach takeoff. For our data, the Analog Technology Substitution Effects for Takeoff Hypothesis (H4a) is not supported. Market competition and technology costs were not significant. So our data do not support the Telecom Market Competition for Takeoff Hypothesis (H2a) or the Technology Use Cost for Takeoff Hypothesis (H3a). The *Asia* and *Europe* dummies were significant, indicating earlier takeoff in those regions though.

Overall, the results suggest that standards, and analog wireless phone penetration are key drivers for takeoff. Countries with one wireless phone standard tend to reach takeoff faster. Similarly, countries that have many analog wireless phone subscribers reach takeoff faster. This result does not support the prediction from product life cycle theory that analog technology substitutes for digital technology though.

Table 3
Results of proportional hazard regression for factors influencing time-to-takeoff.

Variables	Coeff.	Std. err.	Z (signif.)	Hazard ratio
STD	−1.44	0.14	-2.36^{***}	0.24
COMP	0.03	0.15	0.23	1.03
COST	0.007	0.007	1.01	1.01
ANALOG	0.001	0.00003	3.43^{***}	1.00
GINI	0.05	0.03	1.59	1.05
EDU	0.53	0.38	1.39	1.69
Africa	1.71	1.16	1.48	5.53
Asia	3.07	1.22	2.53^{***}	21.61
Europe	4.66	1.49	3.12^{***}	105.42

96 obs., 41 countries. Likelihood ratio, model significance = 29.93^{***}. *Z* tests the hypothesis that a coefficient = 0. Signif.: $^{*}p<.10$, $^{**}p<.05$, and $^{***}p<.01$.

Why? It may be that the extent of analog phone penetration involves cumulative learning that a society achieves with wireless phones. Adopters with an interest in wireless phones who preferred to wait may have adopted soon after digital technology became available. Also, early adopters of an innovation like digital technology are likely to have a lot of experience with similar product categories.

Competition and technology costs were not important to time-to-takeoff. This contrasts with the prediction offered by product life cycle theory. Agarwal and Bayus [2] examined product takeoff, including analog wireless phones in the U.S., and found similar results: prices or costs to users are not so important in explaining takeoff times. Early adopters prior to takeoff are likely to be wealthy and risk-taking individuals who are keen to try new and different technologies as soon as they become available.

Finally, digital wireless phone takeoff was faster in Asia and Europe. The European Union countries agreed to use one standard, GSM. Countries with one standard had faster takeoff. Fewer uncertainties among competitors created spillover effects for higher expectations of payoffs for consumers. A large increase in growth of wireless phone subscribers in Asia seems to have come from the rolling out of prepaid services that made digital wireless phone services more attractive to adopters. In some countries, users embraced wireless phones and various services to enhance their lifestyle. With this knowledge, operators competed to offer a variety of services that matched user needs. For example, users in Japan were among the first to play music, movies, and send pictures and video clips by phone. Users in the Philippines enjoyed innovative services, including wireless-enabled clubs for women, money transfers on wireless phones, and domestic transfers and remittances for wireless subscribers.

6.1.2. Sub-samples

The developed and developing country sub-sample results come next. (See Table 6.) We also evaluated network effects in the sub-sample analysis models. (See Table 7.)

Table 4
Proportional hazard regression results for factors influencing time-to-takeoff controlling for network effects.

Variables	Coeff.	Std. err.	Z (signif.)	Hazard ratio
DIGITAL	−0.003	0.003	−0.97	0.997
STD	−1.63	0.63	-2.59^{***}	0.20
COMP	0.008	0.15	0.06	1.01
COST	0.006	0.007	0.94	1.01
ANALOG	0.002	0.001	2.78^{***}	1.00
GINI	0.05	0.03	1.67^{*}	1.05
EDU	0.79	0.44	1.80^{*}	2.20
Africa	1.55	1.16	1.34	4.69
Asia	2.93	1.20	2.43^{**}	18.66
Europe	4.22	1.50	2.81^{***}	68.17

96 obs., 41 countries. Likelihood ratio, model significance = 29.20^{***}. *Z* tests the hypothesis that a coefficient = 0. Signif.: $^{*}p<.10$, $^{**}p<.05$, and $^{***}p<.01$.

---

[14] The finer scheme classifies countries into nine cultural clusters. These include *Asia Pacific* (Australia, China, Hong Kong, Indonesia, Japan, Korea, Malaysia, New Zealand, Philippines, Singapore, Thailand, Vietnam), *Middle East* (Iran, Kuwait, Saudi Arabia, United Arab Emirates), *South Asia* (Bangladesh, India, Pakistan, Sri Lanka), *Africa* (Egypt, Morocco, South Africa, Sudan, Tanzania, Uganda), *N. America* (USA), *Latin America* (Brazil, Nicaragua), *Mediterranean* (Greece, Portugal), *W. Europe* (Belgium, France, Germany, Netherlands, Switzerland, Turkey, United Kingdom) and *Scandinavia* (Denmark, Finland, Norway).

[15] All the variance inflation factor values are less than 10 (from 1.05 for *COST* to 2.86 for *ANALOG*), indicating that multicollinearity is not an issue. Dropping GDP may lead to loss of explanatory power for wealthy and less wealthy countries. We compensated by performing sub-sample analysis to evaluate systematic differences between the developed and developing countries.

Table 5
Proportional hazard regression results for factors influencing time-to-takeoff using finer classification of cultural clusters.

Variables	Coeff.	Std. err.	Z (signif.)	Hazard ratio
STD	-1.26	0.56	-2.26^{**}	0.28
COMP	0.14	0.18	0.81	1.15
COST	0.02	0.01	2.10^{**}	1.02
ANALOG	0.001	0.00003	3.43^{***}	1.00
GINI	0.05	0.04	1.39	1.05
EDU	0.73	0.47	1.53	2.07
Africa	1.07	1.12	0.96	2.93
Asia Pacific	2.79	1.14	2.46^{**}	16.33
Middle East	2.55	1.17	2.19^{**}	12.80
Mediterranean	5.05	1.34	3.77^{***}	155.99
South Asia	1.69	1.07	1.58	5.43
Western Europe	3.96	1.26	3.15^{***}	52.71
Scandinavia	5.72	1.42	4.02^{***}	303.83
North America	-0.67	2.22	-0.30	0.52

96 obs., 41 countries. Likelihood ratio, model significance = 34.50^{***}. The results of this model are comparable with the model with dummy variables for regions (Africa, Asia, Europe, and America). The model with regional dummy variables found the Asia (including Asia Pacific Middle East and South Asia sub-regions) and Europe (including Mediterranean, Western Europe and Scandinavian countries) regional dummy variables to be positive and significant. The results from this model echo those with Asia Pacific, Middle East, Mediterranean, Western Europe and Scandinavia sub-regional dummy variables to be positive and significant. The χ^2 (d.f. = 5) result of the likelihood ratio test between the model with four regions and the model with nine regions is 8.26 ($p = 0.14$), indicating that there is no significant difference between the two models. *Z* tests the hypothesis that a coefficient = 0. Signif.: ${}^{*}p<.10$, ${}^{**}p<.05$, and ${}^{***}p<.01$.

Similar to the full-sample, estimated coefficients of network effects are not significant for the developed country ($p = 0.11$) and developing country model ($p = 0.91$). So the results from Table 6 are appropriate to interpret. Our sub-sample analysis reflected a few differences between the developed and developing countries. In the case of the developed countries, *ANALOG* was the only significant variable ($p<.01$) with a coefficient of 0.03 and hazard ratio of 1.03. For the developing countries, two significant drivers of takeoff were the number of standards (*STD*) and education (*EDU*). The number of standards was negative with a coefficient of -1.06 and hazard ratio of 0.35 ($p<.05$). Education was positive with a coefficient of 1.43 and a hazard ratio of 4.19 ($p<.05$).

Interestingly, the influential factors for takeoff appear to be different between developed and developing countries. A large pool of analog subscribers in developed countries seems to have played an important role in the takeoff of digital wireless phones. Multiple standards, the lack of highly-educated populations, and lower quality educational services have tended to slow down takeoff in developing countries. This is not surprising because most users in developing countries are first-time phone users. Early adopters tend to be those with higher education; they understand the different standards and their implications for wireless phone use. For example, a recent survey in Egypt and Tanzania found that almost 60% of wireless phone owners have high school or higher education [53].

Table 6
Sub-sample analysis for the proportional hazard regression of takeoff.

	Developed countries				Developing countries			
Var.	Coef.	SE	Z	Hazard ratio	Coef.	SE	Z	Hazard ratio
STD	-0.90	0.93	-0.96	0.31	-1.06	0.51	-2.08^{**}	0.35
COMP	-0.13	0.29	-0.45	0.72	0.09	0.13	0.65	1.09
COST	0.05	0.04	1.28	1.07	0.006	0.007	0.91	1.006
ANALOG	0.03	0.01	2.55^{***}	1.03	0.35	0.23	1.54	1.41
GINI	0.03	0.05	0.55	1.02	-0.01	0.03	-0.54	0.99
EDU	0.82	1.65	0.49	2.51	1.43	0.68	2.12^{**}	4.19

Developed countries: 40 obs., 20 countries. Likelihood, model signif. = 16.58^{***}. Developing countries: 56 obs., 21 countries. Likelihood, model signif. = 23.29^{***}. *Z* tests whether a coefficient = 0. Signif.: ${}^{*}p<.10$, ${}^{**}p<.05$, ${}^{***}p<.01$.

Table 7
Sub-sample analysis for the proportional hazard regression of takeoff controlling for network effects.

	Developed countries				Developing countries			
Var.	Coef.	SE	Z	Hazard ratio	Coef.	SE	Z	Hazard ratio
DIGITAL	-0.10	0.006	-1.67	0.99	0.002	0.02	0.11	1.002
STD	-1.12	0.84	-1.33	0.33	-1.17	0.17	-2.19^{**}	0.31
COMP	-0.33	0.35	-0.96	0.72	0.03	0.31	0.11	1.03
COST	0.03	0.04	0.91	1.03	0.009	0.009	1.08	1.01
ANALOG	0.002	0.001	1.98^{**}	1.002	0.34	0.21	1.62	1.40
GINI	0.02	0.05	0.41	1.02	-0.008	0.05	-0.18	0.99
EDU	0.40	0.82	0.48	1.49	1.21	0.68	1.77^{*}	3.34

Developed countries: 40 obs., 20 countries. Likelihood, model signif. = 14.25^{***}. Developing countries: 56 obs., 21 countries. Likelihood, model signif. = 18.80^{***}. *Z* tests whether a coefficient = 0. Signif.: ${}^{*}p<.10$, ${}^{**}p<.05$, ${}^{***}p<.01$.

6.2. Panel data results of factors influencing penetration growth during the growth phase

We next compare four different random-effects panel data models: (1) direct influences; (2) direct influences and an interaction effect between standards and competition; (3) direct influences controlling for autocorrelation; and (4) direct influences and an interaction effect between standards and competition controlling for autocorrelation. We checked some model diagnostics and endogeneity, however, only heteroskedasticity was present.[16] So we modeled using region and culture cluster dummies in separate runs. The results are comparable with the model with the regional dummy variables. (See Tables 8, 9 and 10.)

6.2.1. Model comparison

The interaction effect between *STD* and *COMP* is not significant in both random effects models ($p = 0.18$) and in the model that controls for autocorrelation ($p = 0.51$). So next, we checked if autocorrelation should be addressed in the direct influence model. The *Baltagi–Wu locally-best invariant* (LBI) *statistic* for the random effects model with autocorrelation is 2.02. A value far below 2 suggests autocorrelation. Since LBI is higher than 2, autocorrelation is not a concern. So we will use the results from the random effects model with direct influences in Table 8, as a basis for interpreting what we observe.

6.2.2. Estimated parameters

STD was negative and significant ($\beta_{STD} = -4.39$, $p<.05$). This supports the Single Standard for Growth Hypothesis (H1b). An additional standard decreases penetration growth by as much as 439%. *COMP* was positive and significant ($\beta_{COMP} = 0.08$, $p<.01$), which supports the Telecom Market Competition for Penetration Growth Hypothesis (H2b). An additional digital wireless phone operator increases penetration growth by a modest 8%. *COST* and *ANALOG* were not significant though. So the Technology Use Cost for Penetration Growth Hypothesis (H3b) and the Analog Technology Substitution Effects

---

[16] We evaluated whether multicollinearity, heteroskedasticity and endogeneity biased the modeling estimates. Multicollinearity increases parameter variance, so the estimates are less precise. We diagnosed multicollinearity by checking pair-wise correlations between the explanatory variables. All of our explanatory variables had correlation coefficients less than 0.7. All VIF values were less than 10 (ranging from 1.02 for *ANALOG* to 1.5 for *STD*), indicating that multicollinearity was not an issue either for the panel data. We used White's test, which uses a Lagrange multiplier that has a χ^2 distribution under the null hypothesis of homoskedasticity. The test results ($\chi^2 = 62.82$, d.f. = 36, $p<0.004$) suggested that heteroskedasticity might be an issue, so we used robust standard errors to correct for it. We also evaluated whether *endogeneity* was present. This problem arises when explanatory variables and a dependent variable are simultaneously determined by some unobservable variables. Technology costs or prices might be determined by subsidies, discounts, quality of services, and network coverage. These omitted variables may influence adoption decisions. We used a Lagrange multiplier test to see if the unobserved error term has a large value, which might hint at the presence of endogeneity, but it was not an issue ($\chi^2 = 1.57$, d.f. = 1, $p = 0.21$).

Table 8
Penetration growth random effects model in growth phase by region.

	Random effects model with direct influences			Random effects model with direct influences and an interaction effect		
Variable	Coef.	Robust SE	*t*	Coef.	Robust SE	*t*
STD	−4.39	2.27	-1.94^{**}	−1.65	0.26	-6.29^{***}
COMP	0.08	0.02	3.52^{***}	0.11	0.04	2.88^{***}
STD×COMP				0.12	0.08	1.48
COST	−0.0004	0.0005	−0.85	−0.001	0.006	−0.17
ANALOG	10.12	9.66	1.05	10.02	9.61	1.04
GDP	0.0003	0.0001	2.55^{**}	−0.001	0.0002	-3.21^{***}
GINI	0.15	0.10	1.55	0.11	0.08	1.30
EDU	2.86	1.32	2.17^{**}	0. 69	0.34	2.03^{**}
Africa	−6.52	4.51	−1.44	−6.45	3.89	−1.66
Asia	−3.19	3.70	−0.86	−3.07	2.70	−1.14
Europe	−2.17	3.21	−0.68	−3.25	3.26	−1.00

313 obs. for 41 countries. Dep. var.: penetration growth during growth phase. Signif.: $^{*}p<.10$, $^{**}p<.05$, and $^{***}p<.01$. Random effects model with direct influences: $R^2=0.27$. Hausman test ($\chi^2=3.42$, $p<0.49$) showed no correlation of country-specific effects with explanatory variables. Thus, a random effects model is suitable. Random effects model with direct influences and interaction effect: $R^2=0.26$. Hausman test ($\chi^2=7.01$, $p=0.22$) also showed no correlation of country-specific effects with explanatory variables. So a random effects model again is appropriate.

for Penetration Growth Hypothesis (H4b) were not supported. Two others, *GDP* and *EDU*, were significant. *GDP* was positive but has little economic influence ($\beta_{GDP}=0.0003$, $p<.05$). A 100 international dollar increase in *GDP* per capita increases growth by 0.03%. *EDU* is positive too ($\beta_{EDU}=2.86$, $p<.05$).

The presence of standards continues to be an important factor to explain high growth during the growth phase after takeoff. High market competition explains penetration growth. Since price was not significant, apparently other non-price factors, such as actual and perceived technological improvements, product differentiation, and innovative services, are more influential drivers of penetration growth.

Next, we performed sub-sample analysis to determine whether there were any noticeable differences between developed and developing countries. Similar to the full-sample analyses, we compared four different random-effects models for the developed and developing countries: (1) direct influences; (2) direct influences and an interaction effect between standards and competition; (3) direct influences controlling for autocorrelation; and (4) direct influences and an interaction effect between standards and competition controlling for autocorrelation. (See Tables 11, 12, 13 and 14.)

6.2.3. Model comparison

For both developed and developing countries, the interaction effects between *STD* and *COMP* were not significant in both random effects models ($p=0.85$ for developed countries; $p=0.82$ for developing countries) and the random effects model controlling for autocorrelation ($p=0.16$ for developed countries and $p=0.12$ for developing countries). The LBIs for the random effects model with autocorrelations are 2.12 and 1.96 for the developed and developing country models. Although the developing country model LBI was lower than 2, its value doesn't suggest autocorrelation is problematic. So it still makes sense to use the results from the random effects model in Table 11 to report our findings.

For the developed countries, four variables are notable. *STD* was negative and significant ($\beta_{STD}=-1.60$, $p<.05$). *COMP* was positive and significant ($\beta_{COMP}=0.08$, $p<.05$), and analog penetration (*ANALOG*) was positive and weakly significant ($\beta_{ANALOG}=16.26$, $p<.10$). *GDP* was negative and significant ($\beta_{GDP}=-0.0002$, $p<.05$). For developing countries, two variables are significant. *STD* was negative, significant ($\beta_{STD}=-2.00$, $p<.10$), and *COMP* was positive and significant ($\beta_{COMP}=0.08$, $p<.01$).

The results suggest that, in addition to standards and competition, an installed base of analog subscribers and wealth drive penetration growth after takeoff for developed countries. Since they introduced analog wireless phones earlier, the phase-out of analog technology was more likely to have happened already in these countries. Wealth reflects a country's economic conditions and its consumers' ability to acquire new technology. Consistent with previous findings in product life cycle research [9] and wireless communications technology [26], individuals in wealthier countries are more likely to adopt new technology faster than those in less wealthy countries.

7. Discussion

Successful diffusion of a new technological innovation in a network-based industry requires an industrial structure and the involvement of several public and private actors to create strong value propositions for the products to consumers. Digital wireless phone technology has been increasingly viewed as a transformative innovation that has made significant contributions to economic and social development for both developed and less developed countries.

Table 9
Penetration growth random effects model by culture clusters.

Variable	Coef.	Std. err.	*t*	Variable	Coef	Std. err.	*T*
STD	−0.86	0.33	-2.60^{***}	*Africa*	−0.38	0.68	−0.55
COMP	0.08	0.04	3.52^{***}	*Asia Pacific*	−0.24	0.71	−0.34
COST	−0.004	0.007	−0.54	*Middle East*	−0.51	0.68	−0.75
ANALOG	26.50	9.06	2.92^{***}	*Mediterranean*	−1.04	0.68	−1.54
GDP	−0.00003	0.00007	-4.41^{***}	*South Asia*	−0.28	0.73	−0.38
GINI	0.01	0.02	0.53	*W. Europe*	−0.74	1.66	−0.45
EDU	0.32	0.17	1.85^{*}	*Scandinavia*	−0.84	0.91	−0.92
				N. America	−0.36	0.67	−0.53

313 observations for 41 countries. Dependent variable: penetration growth during growth phase. $R^2=0.30$. Results comparable with model with dummy variables for regions (Africa, Asia, Europe, and America). No significant effects of these dummies were identified for either model. Signif.: $^{*}p<.10$, $^{**}p<.05$, and $^{***}p<.01$.

Table 10
Penetration growth random effects model controlling for autocorrelation.

Variable	Random effects model controlling for autocorrelation			Random effects model with *STD* × *COMP* effect and controlling for autocorrelation		
	Coef.	Std. err.	*t*	Coef.	Std. err.	*t*
STD	−0.80	0.42	-1.90^{**}	−0.89	0.42	-2.09^{**}
COMP	0.09	0.02	5.68^{***}	0.22	0.005	42.72^{***}
STD × *COMP*				0.16	0.24	0.66
COST	−0.00003	0.001	−0.02	−0.005	0.012	−0.44
ANALOG	23.59	5.84	4.04^{***}	17.83	6.98	2.55^{**}
GDP	−0.0002	0.00005	-3.40^{***}	−0.0001	0.0005	-2.93^{***}
GINI	0.003	0.03	0.07	0.008	0.034	0.23
EDU	1.81	0.55	3.28^{***}	1. 34	0.60	2.21^{**}
Africa	−1.26	1.21	−1.04	−0.41	1.27	−0.32
Asia	−0.99	1.10	−0.90	−0.05	1.26	−0.04
Europe	−0.27	1.29	−0.21	−0.93	1.44	−0.64

313 observations for 41 countries. Signif.: $^{*}p<.10$, $^{**}p<.05$, and $^{***}p<.01$. Random effects model controlling for autocorrelation: $R^2=0.26$. LBI is 2.02. LBI is equivalent to the Durbin–Watson statistic and appropriate for unbalanced panel data. It tests the null hypothesis that $\rho=0$. Since the statistic has a complex distribution, there are no reported critical values for rejecting the null hypothesis. The random effects model with the interaction effect between standards and competition and controlling for autocorrelation: $R^2=0.27$. LBI for the random effects model with autocorrelation is 2.03, so autocorrelation is not a concern. Thus, we will interpret factors that influence penetration growth from the random effects model with direct influences.

7.1. Theoretical and empirical contributions

Our research contributes to theory development on IT diffusion and technology evolution. We have brought together concepts from technology dominance and product life cycle theories to develop a broader view of industry structure necessary to create a successful market of a new network-based innovation. Network-based innovations such as wireless communications technology require knowledge, resources, and competencies that span across firms, governments and countries. The stories of the development of the GSM standard and the adoption of the CDMA standard in South Korea provide illustrative case studies of the need for a broader view of industry structure.

With the backdrop of the existence of five different analog standards in European countries, the European Commission recognized early on that a single digital wireless standard was necessary to unify Europe. The GSM standard was developed in the European Technology Standards Institute (ETSI) through the participation of governments, thirteen European service providers, and more than ten U.S. and European manufacturers. Subsequently, the European Council of Ministers signed the Memorandum of Agreement in 1991, with statements of intention from operators in thirteen different countries to provide digital wireless phone services based on the GSM standard. The adoption of GSM by the European Union was a critical event in the trajectory that led to its dominance among digital wireless phone standards. Firms that participated in the GSM standard-setting effort helped to convince other governments in South America, Asia, and Africa to adopt GSM, thus securing GSM as a widely-adopted global digital standard.

The role that a dominant standard played in creating a successful digital wireless market was also demonstrated in South Korea. Government sponsorship enabled effective coordination of actions among firms. It provided R&D funds to support the development and implementation of CDMA technologies, and established a consortium of leading South Korean manufacturers and operators to work with Qualcomm. These two case studies provide evidence to suggest that a narrow view of industry structure (firm entry, firm exit, competition) is not sufficient to establish an accurate understanding of a network-based industry such as wireless communications technology. The cases also point out the important role of dominant design in the form of standards in establishing the digital wireless industry and market that precedes firm entries and other industry dynamics typically discussed in technology dominance theory.

Consistent with prior work, we found strong support that the presence of a single standard speeds up takeoff and subsequent diffusion growth. Strong market competition through non-price factors drives faster diffusion after takeoff. Standards as a form of dominant design to support industry structure have to be complemented with a related view of standards as infrastructures that support new IT service innovations. A dominant design is a preferred design knowledge and technological hierarchy that is embodied in available products afterward. Infrastructure refers to "the basic information technologies and organizational structures, along with the related services and facilities necessary for an enterprise or industry to function" [51, p. 748]. In the context of wireless communications, standards enable actors (e.g., device manufacturers, operators, and service providers) who may have different private interests to coordinate their actions to develop products that draw strong adopters' interest to the entire industry, thus allowing participating firms to share revenues and profits. Standards enable firms to develop a variety of value-added

Table 11
Sub-sample analysis for penetration growth in the growth phase.

Variable	Developed countries			Developing countries		
	Coef.	Robust SE	*t*	Coef.	Robust SE	*t*
STD	−1.60	0.72	-2.24^{**}	−2.00	1.061	1.90^{*}
COMP	0.08	0.03	2.86^{***}	0.08	0.02	3.24^{***}
COST	0.03	0.02	1.45	−0.07	0.06	−1.21
ANALOG	16.26	9.64	1.69^{*}	3.92	4.31	0.91
GDP	−0.0002	0.0001	-2.31^{**}	−0.0005	0.0005	−1.07
GINI	0.05	0.07	0.78	0.15	0.10	1.42
EDU	0.40	1.05	0.39	0.87	0.84	1.04

Model: random effects. Developed countries: 20; 162 obs.; $R^2=0.36$. Developing countries: 21; 151 obs.; $R^2=0.30$. Signif.: $^{*}p<.10$, $^{**}p<.05$, $^{***}p<.01$.

Table 12
Sub-sample analysis for penetration growth in the growth phase, interaction effect.

Variable	Developed countries			Developing countries		
	Coef.	Robust SE	*t*	Coef.	Robust SE	*t*
STD	−1.75	0.85	-2.06^{**}	−1.21	0.55	-2.20^{**}
COMP	0.11	0.03	3.76^{***}	0.08	0.02	3.27^{***}
STD × *COMP*	0.08	0.43	0.19	0.07	0.45	0.16
COST	0.03	0.02	1.58	−0.07	0.05	−1.25
ANALOG	17.46	7.86	2.22^{**}	4.77	4.53	1.05
GDP	−0.0003	0.0001	-1.96^{*}	−0.0002	0.0002	−1.26
GINI	0.05	0.07	0.62	0.15	0.11	1.30
EDU	0.38	1.10	0.35	0.87	1.03	0.84

Model: random effects. Developed countries: 162 obs., 20 countries. $R^2=0.37$. Developing countries: 151 obs., 21 countries. $R^2=0.30$. Signif.: $^{*}p<.10$, $^{**}p<.05$, and $^{***}p<.01$.

Table 13
Sub-sample analysis for penetration growth in the growth phase, controlling for autocorrelation, for developed countries only.

	Random effects model controlling for autocorrelation			Random effects model with std × comp effect and controlling for autocorrelation		
Variable	Coef.	Robust SE	t	Coef.	Robust SE	t
STD	−0.80	0.19	-4.23^{***}	−2.19	0.12	-18.04^{***}
COMP	0.12	0.03	4.57^{***}	0.29	0.02	18.55^{***}
STD × *COMP*				0.63	0.45	1.42
COST	0.03	0.03	0.77	−0.03	0.03	−0.83
ANALOG	21.79	10.40	2.10^{**}	27.77	8.83	3.14^{***}
GDP	−0.0002	0.0001	-1.73^{*}	−0.0003	0.0001	-2.10^{**}
GINI	0.01	0.09	0.15	0.03	0.10	0.27
EDU	1. 79	1.78	1.00	1. 83	1.77	1.04

Developed countries: 162 obs., 20 countries. Signif.: $^{*}p<.10$, $^{**}p<.05$, and $^{***}p<.01$. The random effects model with controls for autocorrelation: $R^2=0.35$. LBI = 2.12, so autocorrelation is not present. The random effects model with an interaction effect between *STD* and *COMP*, while controlling for autocorrelation: $R^2=0.36$. LBI = 2.12, so again autocorrelation is not a concern. Thus, we can interpret the factors that influence penetration growth for developed countries based on the random effects model.

wireless services such as location-based services, ring tones, and mobile shopping. In some cases, the emergence of a standard is a defining moment that shapes the entire industry. The convergence of the global GSM standard has shaped the competition and demand in digital wireless communications worldwide. The agreement on standards enables the actors to use a strategy of "running with the pack" to develop superior value for digital wireless phone services to adopters [52]. Operators can develop non-price and product differentiation strategies such as coverage, prepaid cards, SIM locking, contractual length, and handset locking to acquire and maintain customers.

Previous research on product life cycles [2,21] has focused on simple consumer products [18], such as refrigerators, answering machines, and dishwashers, that don't require subsystems, processes, or many lines of software code. This research examines more complex, network-based innovations that require firms to think beyond the traditional competitive strategies widely used with consumer products such as entry barriers, channel management, and brand awareness to create demand for their products.

Our findings offer a nuanced understanding of contextual factors in the success of a new innovation. Socio-economic conditions in developing countries, such as levels of education among the general population, may hinder the diffusion of a new innovation. Others have viewed IT diffusion as a process of social change [4]. The lack of progress with the diffusion of new technologies in developing countries may diminish the economic and social benefits and dampen their development potential.

Although our data do not reveal the usage patterns of digital wireless phones across countries, anecdotal evidence offers additional insights on the issue. In emerging economies such as China and India, most new users prefer lower-end services and are price-sensitive. Phone companies with vested interests in a potentially large market in these countries came up with innovative products that catered to the local demand. Nokia, for example, introduced Nokia 1100 low-priced handsets that have flashlights, an alarm clock, a radio, and an anti-slip grip in India. In another group of countries, including Japan and South Korea, wireless phone users enjoy expanded data services and high-end handsets that come with many advanced features. In addition, these users are willing to replace their handsets as soon as new models appear in the market. In South Korea, ten million handsets were replaced in 2003 [13]. Yet, in the least developed countries of Africa, for example, people use wireless phones differently. Wireless phone handsets are often shared among family members or community members in telecenters. Price elasticity of demand is quite high, which suggests that high call charges may inhibit wireless phone usage in these countries [20].

Technology clusters also have played a role in the development of the wireless phone industry. The wireless phone industry consists of at least three distinct areas: technology, services and applications [12]. The *technology area* includes handset, network equipment and other enabling technology companies. The *service area* includes wireless phone operators, virtual operators, and portal providers. Finally, the *application area* includes application developers, application providers, and content providers. Although it might be easier for developing countries to lure foreign direct investment to operate wireless phone services (e.g., Vodafone has a presence in many developing countries worldwide), creating contents that are tailored to local needs requires skilled human capital that might be challenging for the developers of innovative wireless phone services to attract. Thus, the lack of complementary factors, especially skilled human capital and the maturity of the content production industry, might delay the

Table 14
Sub-sample analysis for penetration growth in the growth phase, controlling for autocorrelation, for developing countries only.

	Random effects model controlling for autocorrelation			Random effects model with *STD* × *COMP* effect and controlling for autocorrelation		
Variable	Coef.	Robust SE	t	Coef.	SE	t
STD	−0.64	0.25	-2.52^{**}	−2.64	0.14	-18.33^{***}
COMP	0.06	0.02	2.62^{***}	0.25	0.01	17.99^{***}
STD × *COMP*				5.65	3.65	1.55
COST	−0.06	0.09	−0.76	−0.05	0.09	−0.63
ANALOG	1.56	0.73	2.15^{**}	3.79	3.47	1.09
GDP	−0.0007	0.0007	−1.07	−0.0007	0.0007	−1.05
GINI	0.24	0.23	1.04	0.19	0.23	0.81
EDU	5.36	5.15	1.04	4. 84	5.19	0.93

Developing countries: 151 obs., 21 countries. Signif.: $^{*}p<.10$, $^{**}p<.05$, and $^{***}p<.01$. The random effects model controlling for autocorrelation: $R^2=0.32$. LBI = 1.96; autocorrelation may be present but does not seem to be a serious concern. The random effects model with an interaction between *STD* and *COMP*, while controlling for autocorrelation: $R^2=0.36$. LBI = 1.95. Since the interaction is not significant, the results of penetration growth in the growth phase in developing countries can be reported using the random effects model. Controlling for autocorrelation to maximize confidence in the estimates will have little added benefit, based on our results.

takeoff and further penetration growth in developing countries of digital wireless phone services.

7.2. Managerial and policy implications

This study offers three insights for wireless phone operators and others in the wireless phone value network to develop successful strategies in the life cycle of the innovations. Firms need to pursue dual innovation strategies at the industry and at the firm level. At the industry level, companies need to participate in standards development to build their own knowledge and coordinate with others to develop necessary wireless infrastructure and technological capabilities. These collective activities are an important initial step to stimulate user demand. As demand is built up, firms need to use their innovative capabilities to differentiate their services (e.g., coverage, pre-paid services) from other players in order to entice users to choose their services. A transitional period of technological change also allows operators to capture the previous generation users through appealing value-added services or new product functionalities.

From a policy perspective, standardization and industrial policies are critical to develop and maintain an innovative industry. In the early life cycle of innovations, standardization reduces market uncertainty and encourages industry-wide efforts to support and enable technology development necessary for takeoff to occur. To facilitate further market growth, strong competition induces industry players to constantly experiment with new ideas to offer novel services at competitive price points.

8. Conclusion

This research developed and empirically tested a theoretical model with standards, market competition, technology cost, and technology substitutes. Our goal was to understand takeoff and penetration growth during the growth phase of digital wireless phones. Standards appear to be important across the introduction and growth phases. Familiarity with wireless phone technology and a large installed base of analog technology also explain faster takeoff times. Non-price factors, in contrast, seem to be the important drivers of penetration growth during the growth phase. The results are useful for regulators in countries not yet offering 3G licenses. For operators, we see that non-price factors are more important than price factors to explain high penetration growth. Thus, operators should focus their effort on creating innovative services with new technological features. Policy-makers in developing countries also need to invest in educational programs about the benefits of digital wireless phones to family life and work.

Our takeoff theory suggests that critical mass is a precondition for a new IT to take off. Our proposed theory can explain the takeoff of a new IT and further penetration growth. It can be applied to understand the takeoff of other ITs in the same class as wireless phones. Some that come to mind are wireless connection technology, HDTV and 3DTV. The theoretical model is valid for studying technology takeoff in different settings — including within a country too.

Similar to other international studies, we faced the problem of missing data. The lack of wireless phone subscriber data from countries in Latin America continues to be troublesome, and it prevented us from having more of these countries in our sample. Another limitation is that, although the costs to use digital wireless phones involve handset cost, one-time connection charges, and monthly subscription fees, and usage fees, our cost variable captures only variable usage cost. Our cost variable is conservative for countries where operators do not subsidize handsets or have high connection fees.

Finally, consideration must be given to generalizing the theory and findings beyond the countries that we included in this study to other countries in which they may be relevant. Lee and Baskerville [37, p. 237] refer to this type of generalizability as *generalizing from theory to description*. They claim that one should not focus only on *statistical sampling-based generalizability*. They indicate that "the generalizability of the theory to a description of the results that the practitioner would observe if he were to use the theory in a new setting … a setting other than the one(s) where the theory was empirically tested … is arguably the most important form of generalizability in business-school research."

Acknowledgments

An earlier version of this article appeared in the *Proceedings of the 28th International Conference on Information Systems*, Montreal, Canada, in December 2007, where it was recognized as one of the group of papers selected as Best Paper Award Finalists. We thank DSS special issue editors, Yabing Jiang, Jennifer Zhang and Avi Seidmann, as well as the anonymous reviewers, for their support and helpful comments to improve the quality of our work. Rob Kauffman's work on this project was partly supported in his role as the Lee Kuan Yew Faculty Fellow for Research Excellence at Singapore Management University, and previously as the W.P. Carey Chair in Information Systems at Arizona State University.

Appendix A. Data and data collection

We use annual data on countries in Africa, Asia, Europe, Middle East, North America, and Latin America. The 41 countries include 20 developed and 21 developing countries. The countries are Australia, Bangladesh, Belgium, Brazil, China, Denmark, Egypt, Finland, France, Germany, Greece, Hong Kong, India, Indonesia, Iran, Japan, Korea, Kuwait, Malaysia, Morocco, The Netherlands, New Zealand, Nicaragua, Norway, Pakistan, Philippines, Portugal, Saudi Arabia, Singapore, South Africa, Sri Lanka, Sudan, Switzerland, Tanzania, Thailand, Turkey, Uganda, United Arab Emirates, United Kingdom, United States, and Vietnam. We have data since the first introduction year of digital wireless phones in countries up to 2003, except Indonesia and Pakistan up to 2002, and New Zealand up to 2001. The number of data points is different across countries depending on how early they began offering digital wireless phone services. The developed countries were pioneers. Denmark, Finland, and France introduced these services in 1992. The developing countries introduced digital wireless phone services up to five years later.

We also collected phone subscriber and tariff data from the *Yearbook of Statistics* of the International Telecommunication Union. GDP per capita and the GINI index (measuring inequality in national income distribution) are from the World Bank's World Development Indicator Database. Data for standards and market competition are from GSM World, CDMA Development Group, and *Cellular News*. Data for education are from the 2004–2005 Global Competitiveness Report by the World Economic Forum.

A challenge of empirical research with international data involving telecom and economic development-related impacts is the limited length of the time-series that can be obtained for the countries, and whether it is possible to establish commonality of coverage across different countries. The sources of our data were often varied. Another problem is that some variables will be available during some years for some countries, while the same variables may not be available during the same years for other countries. As a result, it is necessary to make choices about the *data rectangles* to be used. We wish to learn from data involving many countries but relatively few explanatory variables (a taller and narrower data rectangle) versus data involving fewer countries but more variables (a shorter and wider data rectangle). Our choice to use 41 countries in this study reflects our effort to balance the height and width of the data rectangles that we worked with, as a basis for providing meaningful evidence. A related problem is the reporting lags that characterize the data, an issue with international data sets involving IT for development.

Table B1
Test of the proportional hazard assumption.

Variable	ρ	χ^2	p
STD	0.08	0.23	0.63
COMP	0.12	0.44	0.51
COST	0.01	0.01	0.94
ANALOG	−0.09	0.34	0.56

Appendix B. Proportional hazard model fit

We checked for a proportional hazard by testing the null hypothesis that the slope of a generalized linear regression of scaled Schoenfeld residuals is zero. Rejecting it indicates that this assumption is violated. The test results of all explanatory variables were insignificant though, indicating the proportional hazard assumption and the model are appropriate. We plotted the deviance residuals to evaluate model fit. The *deviance residuals*, indicating the deviance contribution from each observation, were symmetric around zero. Similar to residual plots in regression models, the deviance residual plots against the linear predictors of the explanatory variables should resemble white noise, if the fit is adequate. This is what we found. (See Table B1.)

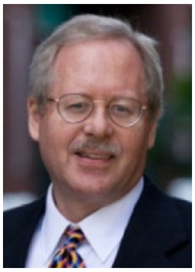
References

[1] R. Adner, D. Levinthal, Demand heterogeneity and technology evolution: implications for product and process innovation, Management Science 47 (5) (2001) 611–628.
[2] R. Agarwal, B. Bayus, The market evolution and sales takeoff of product innovations, Management Science 48 (8) (2002) 1024–1041.
[3] P. Anderson, M. Tushman, Technological discontinuities and dominant designs: a cyclical model of technological change, Administrative Science Quarterly 35 (4) (1990) 604–633.
[4] M. Barrett, S. Jarvenpaa, L. Silva, G. Walsham, ICTs, globalization and local diversity, Communications of the Association for Information Systems 11 (1) (2003) 486–497.
[5] B. Bayus, An analysis of product lifetimes in a technologically dynamic industry, Management Science 44 (6) (1998) 763–775.
[6] S. Bhatacharjee, R.D. Gopal, K. Lertwachara, J.R. Marsden, R. Telang, The effect of digital sharing technologies on music markets: a survival analysis of albums on ranking charts, Management Science 53 (9) (2007) 1359–1374.
[7] D. Birke, P. Swann, Network effects and the choice of mobile phone operator, Journal of Evolutionary Economics 16 (2006) 65–84.
[8] F. Caselli, W. Coleman II, Cross-country technology diffusion: the case of computers, American Economic Review 91 (2) (2001) 328–335.
[9] D. Chandrasekaran, G. Tellis, Global takeoff of new products: culture, wealth, or vanishing differences? Marketing Science 27 (5) (2008) 844–860.
[10] J. Dedrick, K.L. Kraemer, G. Linden, The distribution of value in the mobile phone supply chain, Telecommunications Policy 35 (6) (2011) 505–521.
[11] S. Dewan, K. Kraemer, Information technology and productivity: evidence from country-level data, Management Science 46 (4) (2000) 548–562.
[12] UMTS Report: An Investment Perspective, Durlacher Research, London, UK, 2001.
[13] Cellular Communications Services in South Korea, Euromonitor International, London, UK, 2004.
[14] C. Forman, A. Gron, Vertical integration and information technology investment in the insurance industry, Journal of Law, Economics, and Organization 27 (1) (2011) 180–218.
[15] L. Fuentelsaz, J. Maicas, Y. Polo, Switching costs, network effects, and competition in the European mobile telecommunication industry, Information Systems Research 23 (1) (2012) 93–108.
[16] J. Funk, The product life cycle theory and product line management: the case of mobile phones, IEEE Transactions on Engineering Management 51 (2) (2004) 142–152.
[17] J. Funk, The emerging value network in the mobile phone industry: the case of Japan and its implications for the rest of the world, Telecommunications Policy 33 (1–2) (2009) 4–18.
[18] J. Funk, Complexity, critical mass and industry formation: a comparison of selected industries, Industry and Innovation 17 (5) (2010) 511–530.
[19] J. Funk, D. Methe, Market and committee-based mechanisms in the creation and diffusion of global industry standards: the case of mobile communication, Policy Review 30 (4) (2001) 589–610.
[20] C. Garbacz, H. Thompson, Demand for telecommunication services in developing countries, Telecommunications Policy 31 (5) (2007) 276–289.
[21] P. Golder, G. Tellis, Will it ever fly? Modeling the takeoff of really new consumer durables, Marketing Science 16 (3) (1997) 256–270.
[22] P. Golder, G. Tellis, G. Growing, Growing, gone: cascades, diffusion, and turning points in the product life cycle, Marketing Science 23 (2) (2004) 207–218.
[23] J. Goo, Y. Song, R. Kishore, K. Nam, H.R. Rao, An investigation of the factors that influence the duration of IT outsourcing relationships, Decision Support Systems 42 (4) (2007) 2107–2125.
[24] M. Grajek, Estimating network effects and compatibility: evidence from the Polish mobile market, Information Economics and Policy 22 (2) (2009) 130–143.
[25] V. Grover, K. Lyytinen, A. Srinivasan, B. Tan, Contributing to rigorous and forward thinking explanatory theory, Journal of the Association for Information Systems 9 (2) (2008) 40–47.
[26] H. Gruber, F. Verboven, The evolution of markets under entry and standards regulation: The case of global mobile telecommunications, International Journal of Industrial Organization 19 (7) (2001) 1189–1212.
[27] H. Gruber, F. Verboven, The diffusion of mobile telecommunications services in the European union, European Economic Review 45 (3) (2001) 577–588.
[28] H. Hoppe, The timing of new technology adoption: theoretical models and empirical evidence, The Manchester School 70 (1) (2002) 56–76.
[29] R.J. Kauffman, A.A. Techatassanasoontorn, Understanding early diffusion of digital wireless phones, Telecommunications Policy 33 (8) (2009) 432–450.
[30] R.J. Kauffman, B. Wang, Tuning into the digital channel: evaluating business model fit for Internet firm survival, Information Technology and Management 9 (3) (2008) 215–232.
[31] R.J. Kauffman, J.J. McAndrews, Y.M. Wang, Opening the "black box" of network externalities in network adoption, Information Systems Research 11 (1) (2000) 61–82.
[32] R.J. Kauffman, A.A. Techatassanasoontorn, B. Wang, Event history, spatial analysis and count data methods, Information Technology and Management 13 (3) (2012) 115–147.
[33] N. Kim, J. Han, R. Srivastava, A dynamic IT adoption model for the SOHO market: PC generational decisions with technological expectations, Management Science 48 (2) (2002) 222–240.
[34] S. Klepper, Entry, exit, growth, and innovation over product life cycle, American Economic Review 86 (3) (1996) 562–583.
[35] S. Klepper, E. Graddy, The evolution of new industries and the determinants of market structure, The Rand Journal of Economics 21 (1) (1990) 27–44.
[36] H. Koski, T. Kretschmer, Entry, standards and competition: firm strategies and the diffusion of mobile telephony, Review of Industrial Organization 26 (1) (2005) 89–113.
[37] A. Lee, R.L. Baskerville, Generalizing generalizability in information systems research, Information Systems Research 14 (3) (2003) 221–243.
[38] B. Lim, M. Choi, M. Park, The late takeoff phenomenon in the diffusion of telecommunication services: network effect and the critical mass, Information Economics and Policy 15 (4) (2003) 537–557.
[39] L. Loh, N. Venkatraman, Diffusion of information technology outsourcing: influence sources and the Kodak effect, Information Systems Research 3 (4) (1992) 334–358.
[40] C. Maitland, J. Bauer, R. Westerveld, The European market for mobile data: evolving value chains and market structure, Telecommunications Policy 26 (9–10) (2002) 485–504.
[41] R. Montealegre, Temporal model of institutional interventions for information technology adoption in less-developed countries, Journal of Management Information Systems 16 (1) (1999) 207–232.
[42] M. Myers, F. Tan, Beyond models of national culture in information systems research, Journal of Global Information Management 10 (1) (2002) 24–32.
[43] P. Rosenzweig, When can management science research be generalized internationally? Management Science 40 (1) (1994) 28–39.
[44] P. Rouvinen, Diffusion of digital mobile telephony: are developing countries different? Telecommunications Policy 30 (1) (2006) 46–63.
[45] L. Silva, E.B. Figueroa, Institutional intervention and the expansion of ICTs in Latin America: the case of Chile, Information Technology and People 15 (1) (2002) 8–25.
[46] M. Srite, E. Karahanna, The role of espoused national cultural values in technology acceptance, MIS Quarterly 30 (3) (2006) 679–704.
[47] S. Stremersch, E. Muller, R. Peres, Does new product growth accelerate across technology generations? Marketing Letters 21 (2) (2010) 103–120.
[48] D. Talukdar, K. Sudhir, A. Ainslie, Investigating new product diffusion across products and countries, Marketing Science 21 (1) (2002) 97–114.
[49] R. Telang, P. Boatwright, T. Mukhopadhyay, A mixture model for Internet search engine visits, Journal of Marketing Science 41 (2) (2004) 206–214.
[50] G. Tellis, S. Stremersch, E. Yin, The international takeoff of new products: the role of economics, culture, and country innovativeness, Marketing Science 22 (2) (2003) 188–208.
[51] D. Tilson, K. Lyytinen, C. Sorenson, Digital infrastructures: the missing IS research agenda, Information Systems Research 21 (4) (2010) 748–759.
[52] A. Van de Ven, Running in packs to develop knowledge-intensive technologies, MIS Quarterly 29 (2005) 365–378.
[53] Africa: the impact of mobile phones, Policy Paper Series 2, Vodafone, Newbury, UK, 2005.
[54] G. Walsham, Cross-cultural software production and use: a structurational analysis, MIS Quarterly 26 (4) (2002) 359–380.
[55] P. Windrum, Heterogeneous preferences and new innovation cycles in mature industries: the amateur camera industry 1955–1974, Industrial and Corporate Change 14 (6) (2005) 1043–1074.
[56] Y. Yoo, K. Lyytinen, H. Yang, The role of standards in innovation and diffusion of broadband mobile services: the case of South Korea, Journal of Strategic Information Systems 14 (3) (2005) 323–353.
[57] K. Zhu, K. Kraemer, Post-adoption variations in usage and value of e-business by organizations: cross-country evidence from the retail industry, Information Systems Research 16 (1) (2005) 61–84.

[58] K. Zhu, S. Dong, S. Xu, K. Kraemer, Innovation diffusion in global contexts: determinants of post-adoption digital transformation of European companies, European Journal of Information Systems 15 (6) (2006) 601–616.

[59] K. Zhu, K. Kraemer, S. Xu, The process of innovation assimilation by firms in different countries: a technology diffusion perspective, Management Science 52 (10) (2006) 1557–1576.

Angsana A. Techatassanasoontorn is a Senior Lecturer of Business Information Systems in the Faculty of Business and Law at Auckland University of Technology, New Zealand. Her research interests include IT-enabled social innovations, IT use and quality of life, digital infrastructure, adoption and diffusion of technology, safe computing, and technology policy. She has published in *Telecommunications Policy*, *AIS Transactions on Human Computer Interaction*, *Electronic Commerce Research and Applications*, *IEEE Security and Privacy*, *Information Technology and Management*, the *Journal of the Association for Information Systems*, and the *Journal of Global Information Management*. Her research has been supported by grants from the Association for Computing Machinery, the Commonwealth Fund Foundation, Internet New Zealand, Microsoft, the National Science Foundation and Qualcomm. She won the prestigious United States National Science Foundation CAREER Award in March 2011 for her research on broadband telecommunication use and its consequences on human quality of life. She also has received best paper awards for her research at the Hawaii International Conference on Systems Science (2004) and AIS Transactions on Human and Computer Interaction (2010). She was a recent recipient of her college's best teacher award in 2011.



Robert J. Kauffman is the Lee Kuan Yew Faculty Fellow for Research Excellence, and Professor of Information Systems and Strategy at the School of Information Systems and the Lee Kong Chian School of Business at Singapore Management University. He also serves as Associate Dean for Research, and Deputy Director of the Living Analytics Research Center. He recently was a Distinguished Visiting Fellow at the Center for Digital Strategies of the Tuck School of Business, Dartmouth College. He has served at Arizona State University, the University of Minnesota, New York University and the University of Rochester. His work has appeared in *Information Systems Research*, *IBM Research and Development Journal*, *Management Science*, the *Journal of Management Information Systems*, the *Review of Economics and Statistics*, *Telecommunications Policy*, *Decision Support Systems*, *Electronic Commerce Research and Applications* and *MIS Quarterly*. He has received awards in multiple disciplines for his research innovations. He recently completed a special issue of *Cornell Hospitality Quarterly* on information and IT strategy, and the *Journal of Management Information Systems* on competitive strategy, economics and IT.