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Competition effect of a new mobile technology on an incumbent technology: An Indian case study

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ABSTRACT

Changes in mobile technology have radically altered people's lives by improving their ability to communicate. New mobile technologies in the market offer enhanced voice capability, high-speed data service, and expanded service coverage. In India, the spread of second-generation mobile technologies—global system for mobile (GSM) and code division multiple access (CDMA)—has led to a dramatic rise in teledensity, from approximately 1% in 1985 to 76.86% in 2011. This presents an interesting opportunity to study the competitive effects of the two technologies. In this paper, we analyze the effect of a new technology (CDMA) on an existing technology's (GSM) diffusion process and vice versa using an epidemic diffusion model that incorporates the competition effect. The results showed that the diffusion of CDMA was faster than that of GSM in India and CDMA diffusion had a positive effect on GSM. Further, despite competition, GSM continues to remain the dominant mobile technology in India. These findings offer useful insights into the diffusion process of mobile telephony in countries with multiple technology standards. They can potentially guide the design of diffusion strategies for future generations of mobile technology.

1. Introduction

Advancements in mobile technology have radically changed people's lives. Each new generation of mobile technology is characterized by improvements such as enhanced voice capability, high-speed data service, better spectrum management, and wider coverage (Table 1). These technological enhancements have not only widened the mobile market but also contributed to making newer mobile applications feasible and affordable, thus enabling faster diffusion of mobile telephony.

A significant development in the evolution of mobile technology is the change in the mode of signal transmission (analog vs. digital) from the first generation to the next. Another equally important change pertains to the access mechanism used. The spectrum is divided into frequency bands, referred to as channels, which are allocated to different users. On the basis of allocation, three different access mechanisms can be identified: frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA) (Gruber, 2005). Digital (i.e. 2G) mobile technology has been introduced globally under different technological variants that can be divided into two major standards: GSM and CDMA. Of the two, GSM is more popular and still enjoys more than 80% of the market share worldwide. Most of the

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Table 1
Generations of mobile technology.

Characteristics	First generation (1G)	Second generation (2G)	Third generation (3G)	Fourth generation (4G)
Signal	Analog	Digital	Digital	Digital
Switching	Circuit switched	Circuit switched	Packet and circuit switched	Packet switched
End application	Basic voice telephony	Voice plus basic data applications	Data and multimedia applications	All IP-based
Speed	Low capacity	Low data speed	Medium data rates	More advanced multimedia applications
Standards	Advanced mobile phone service (AMPS)	Code division multiple access (CDMA), personal digital communications (PDC), global system for mobile communications (GSM)	Wideband CDMA, CDMA 2000, time division synchronous CDMA (TD-SCDMA)	Orthogonal frequency-division multiplexing (OFDM), multi-carrier CDMA
Coverage	Limited local and regional coverage	Global coverage	Global coverage	Global coverage

European Union countries have adopted GSM, while other countries including India, US, Canada, Japan and China have a competitive environment, where more than one standard vie for consumer attention (Gandal, Salant & Waverman, 2003; Casey & Töyli, 2012). Some of the countries such as Japan and Korea have not adopted GSM as a national standard. The Korean government pushed the decision to adopt CDMA standard in Korea whereas Japan had its own Personal Digital Cellular (PDC) standard (based on TDMA) and CDMA (Jho, 2007; Funk, 2009).

Telecommunication is one of the fastest growing sectors in India. While various factors are responsible for this growth (Gupta & Jain, 2012), competitive technologies have significantly contributed to expanding the market. Since the launch of CDMA in 2002, the Indian mobile market has witnessed stiff competition between GSM, which continues to enjoy popularity among the users, and CDMA, which is fast gaining ground owing to the collaborative efforts of CDMA operators, device manufacturers, and technology facilitators. Although the competition between GSM and CDMA has resulted in benefits for end users, its effects on the overall diffusion of mobile telephony in India have not been closely examined.

Majority of the empirical studies on mobile telephony diffusion have typically focused on a single technology (Botelho & Pinto, 2004; Chaddha & Chitgopekar, 1971; Gamboa & Otero 2009; Michalakelis, Varoutas, & Sphicopoulos, 2008; Singh, 2008). The interactions between new and existing technologies within a technological generation (i.e., intragenerational technology competition) have scarcely been explored. In the same vein, the impact of existing technologies on the survival and diffusion process of a new technology or vice versa has not been adequately discussed in academic literature. The capital intensive nature of mobile technology involving heavy investment puts the financial stakes of mobile service providers and policy stakes of the government at risk. Therefore an investigation into the effect of a new technology on an incumbent technology is necessary to determine their survival pattern. This paper explores how each mobile technology, GSM and CDMA, influences the other's diffusion process in an attempt to clarify the diffusion process of mobile telephony as a whole in India. We use an epidemic diffusion model, which incorporates the competition effect, to investigate the interaction effects of GSM and CDMA. The findings will assist all the stakeholders in reducing their risk and enable them to correct their further course of action. They can also be used by policymakers to frame guidelines that facilitate the rapid diffusion of mobile telephony, as well other allied technologies throughout the country.

This rest of the paper is organized as follows. Section 2 presents an overview of mobile telephony in India. In Section 3, the relevant literature is reviewed. Section 4 discusses the research methodology and the diffusion models adopted in the study. The analysis and findings are presented in Section 5. Sections 6 and 7 present the discussion and policy implications respectively followed by conclusions in Section 8.

2. Overview of mobile telephony in India

Digital mobile telephony with GSM technology was introduced in India in 1995. Since then a number of technological and policy reforms have fueled the rapid growth of the telecom sector. The National Telecom Policy of 1994 was an important milestone in the evolution of Indian mobile services as it allowed private players to enter the wireline and mobile sector. Today, the Indian mobile sector has three types of players: public sector companies (BSNL and MTNL), private Indian companies (Reliance Communications, Tata Teleservices), and companies with foreign investments (Vodafone, Bharti Tele-Ventures, Escotel, Idea Cellular, BPL Mobile, and Spice Communications). Of these, the prominent GSM technology operators are Airtel, Vodafone, and Idea Cellular. Reliance Communications and Tata Indicom are the two major CDMA technology operators. In fact, India is the second largest CDMA market in the world. The 42% drop (Fig. 1) in CDMA tariffs within one and a half years of its launch made the service more affordable to the masses (International Telecommunication Union, 2006).

At the end of financial year 2010–2011, India had a total of 811.59 million subscribers, of which 698.37 million (86.05%) were GSM subscribers and 113.22 million (13.95%) were CDMA subscribers (Telecom Regulatory Authority of India, 2011). The ratio of GSM to CDMA subscribers is shown in Fig. 2. Over the years, technological and policy reforms have transformed

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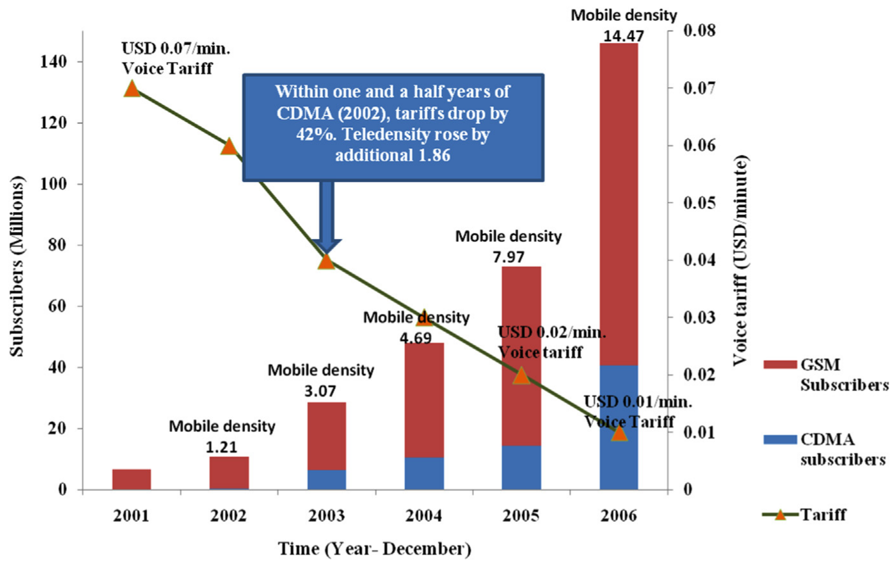

Fig. 1. Reduction in tariff rates after CDMA launch. *Source*: CDMA development group (CDG).

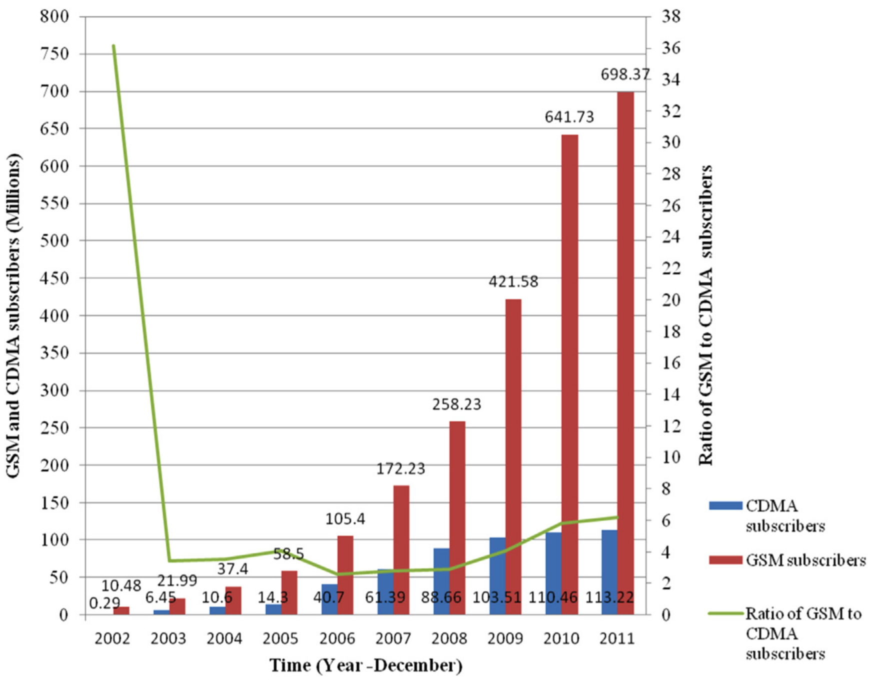

Fig. 2. Growth in wireless subscriber base. *Source*: Performance indicator reports (Telecom Regulatory Authority of India).

telecommunication in India from a static, monopolistic industry that provides a single service to a dynamic multiproduct, multiservice provider.

3. Literature review

Technology diffusion, which involves the dissemination of technical information and know-how and the subsequent adoption of new technologies by potential adopters, follows an S-shaped curve. Numerous studies have examined the diffusion patterns of mobile telephony and the social, technological, economical, and political factors affecting these patterns in different countries (Frank, 2002; Gupta & Jain, 2012; Hwang, Cho, & Long, 2009; Massini, 2003). Massini (2003) found that the introduction of digital technology led to a significant increase in the number of Italian mobile service subscribers. Gupta and Jain (2012) reported that competition among service providers and the removal of receiving party pays (i.e., calling party pays) improved the diffusion rate of mobile telephony in India. Both these studies focused on the diffusion of a single technology within a single generation. Gruber and Verboven (2001) studied multiple technologies (standards) within the analog generation of mobile telephony and showed that competing standards tend to slow diffusion, whereas the diffusion process appears to be faster in markets with a single standard. Their study employed two widely used epidemic models, logistic and Gompertz, to study the diffusion process. They suggested that the existence of multiple technologies increases confusion among the adopters, which results in delayed technology adoption. Kauffman and Techatassanasoontorn (2004) in their research of diffusion of wireless technology (till year 1999) studied 46 countries in Europe, Asia (including India), Africa, and North America. They found that multiple digital wireless standards significantly slow down the diffusion growth. Rouvinen (2006) in their study of diffusion of digital mobile telephony across 165 countries (till year 2000) also indicated similar findings. However, these studies were conducted at very early phase of digital wireless telephony in India whereas coexistence of multiple standards within 2G (GSM and CDMA) started in India from year 2002. Koski and Kretschmer (2005) studied the diffusion of 2G for a panel of 25 industrialized countries and found that standardization accelerates diffusion of 2G. Kano (2000) in their study observed that North America (with multiple standards) presented less penetration of mobile (in year 1998) as compared to Western Europe and Japan (with single standard). Jang, Dai, and Sung (2005) studied the diffusion of mobile telecommunications in 29 OECD countries and identified U.S., Mexico, Canada and Japan as nations with low diffusion rates. Casey and Töyli (2012) found that rapid diffusion of mobile voice call service in Finland could be largely attributed to the harmonized expansion of the GSM standard. Recently, Vialle, Song, and Zhang (2012) analyzed the competition between mobile standards in China for 2G and 3G using case study method. In china, within 2G, GSM was launched in 1994 by China Unicom with CDMA being offered from 1998 in some cities (nationwide CDMA in 2001). Vialle et al. (2012) in their research identified that timing disadvantage due to a late launch in the market, lack of services, increasing returns of information (brand name of China Mobile), and high cost of CDMA handsets resulted into less customer base of CDMA, resulting into dominance of GSM standard.

Researchers have also studied the effect of newer generation technologies by modifying the basic epidemic model (Kim, Chang, & Shocker, 2000; Norton & Bass, 1987; Udayan & Bardhan, 2008). Norton and Bass (1987) developed a multi-generational substitute diffusion model and used it to explore the substitution and diffusion of products like dynamic random-access memory (DRAM) and static random-access memory. Kim et al. (2000) studied the wireless telecom service in Hong Kong on the basis of four devices: the pager, analog mobile telephone, digital mobile telephone, and CT2 (Cordless Telephone). They found that pagers supported the cellular phone market by allowing potential consumers to sample some of the benefits of wireless communication. However, cellular phones seemed to have a negative impact on the market potential for pagers. Growth in CT2 subscriptions expanded the market for pagers and digital cellular phones. Udayan and Bardhan (2008) analyzed four industries (semiconductor, mainframe, television [in India], and wireless [in USA]) by studying two generations of televisions (black & white and color), six generations of DRAM (4 K, 16 K, 64 K, 256 K, 1 M and 4 M), and two generations of mobile phones (analog and digital). They examined the dynamic behavior of the innovation and imitation coefficients across generations and found that the imitation effect increases during later generations. Both these studies focused on new generation technologies that eventually substituted the older one. More recently, Annafari, Lindmark, and Bohlin (2012) studied the intergenerational effects of technology for mobile service diffusion in Sweden between 0G (Mobiltelefonisystem A (MTA)), 1G (Nordic Mobile Telephone (NMT)), 2G (GSM) and 3G technology (Universal Mobile Telecommunications System (UMTS)). They found that each type of technology has a different market potential, and newer technology has greater market potential than older technology. However these studies have not considered technologies competing within a single generation. Further, most of the prior diffusion models, based on the work of Bass (1969), and its extensions (Kim et al., 2000; Norton & Bass, 1987; Udayan & Bardhan, 2008) assume a monopolistic market; in other words, the models are not suited to analyzing interactive competitive markets.

Literature on competing technologies is rare, and very few models that consider the interaction effect of competing technologies have been developed to date. Lotka (1925) and Volterra (1926) developed a system of differential equations for analyzing technological interactions and identified three modes of interaction: pure competition (in which both technologies have a negative effect on each other's growth rate), symbiosis (in which both technologies have a positive effect on each other's growth rate), and a predator–prey mode (in which one technology has a positive effect on the other's growth rate and the second technology has a negative effect on the growth rate of the first). Considered to be a very practical model, a number of studies have adopted it to illustrate the realities of competition. For instance, Maurer and Huberman (2003) employed the Lotka–Volterra model to explore the competitive dynamics of websites and how it affects the market. Kim, Lee, and Ahn (2006) explored the Korean mobile phone market within 2G (cellular and Personal Communication System (PCS)) and found a set of commensalistic relationships in which the PCS market benefits from the existence of the cellular market, while the number of cellular subscribers is hardly affected by the PCS market. Chiang and Wong (2011) also used the Lotka–Volterra model to determine the diffusion of personal computers in Taiwan by considering the competition between desktop computers and notebook computers. Kreng and Wang (2011) identified a predator–prey relationship between liquid crystal display and plasma display panel television sets. Recently, Tseng, Liu and Wu. (2014) used the Lotka–Volterra model to analyze the competition between four smartphone operating systems (Android, iOS, Symbian, and Blackberry). However, to date, this model has been scarcely employed to study the telecommunication technologies existing within a generation.

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4. Research methodology

This study is based on empirical research. The research methodology was designed to identify a competition diffusion model to study the interaction effects of GSM and CDMA technologies in India.

4.1. Epidemic diffusion model

An S-curve epidemic diffusion model was selected to study the diffusion patterns of GSM and CDMA and analyze their competitive effects. The epidemic diffusion model is based on the premise that information drives technology diffusion (Geroski, 2000). It assumes that immediate adoption by potential adopters is hindered by the lack of information about the merits of a technology (how to use it and what it does). In other words, the primary factor limiting diffusion is information, and the most important source of information is the people who have adopted or tried the technology. The epidemic model assumes that a slow initial diffusion process is followed by an epidemic-like effect induced by an accelerated flow of information about the merits of the technology from current adopters to potential adopters. For instance, individual adopters of mobile technologies may discuss its benefits in informal social networks, thus exposing potential adopters to the technology. Opinions, decisions, and behavior are affected by these interactions, which result in a contagious spread of information (Gupta & Jain, 2012, 2014). As an outcome, the perceived risks (fear) and costs decrease, and expedited technology diffusion follows.

In India, most people do not understand or have sufficient information about the various aspects of mobile telephony; therefore, the use of the epidemic model is suitable (Gupta & Jain, 2012). The two epidemic models – logistic and Gompertz – allow for capturing of network externalities, which is an important feature of mobile telephony.

4.1.1. Logistic diffusion model: single technology

The logistic diffusion model for a single technology is expressed in Eq. (1):

$$\frac{dN\,(t)}{dt} = qN\,(t)\left[1 - \frac{N(t)}{\overline{N}}\right] \tag{1}$$

where $N(t)$ denotes the number of subscribers at time t, q denotes the technology diffusion rate (intrinsic growth rate), and $\overline{N}$ denotes the saturation level. The rate of growth in the number of subscribers is influenced by both the number of existing subscribers and the difference between the saturation level and the number of subscribers (the amount of growth remaining to be accomplished).

4.1.2. Logistic diffusion model: multiple technologies

If two competing technologies do not differ much from each other, the diffusion of one might affect that of the other. In this study, we focus on two competing mobile technologies in India, GSM and CDMA, which provide similar services to users. The coexistence of the two technologies influences each other's diffusion process. The influence of CDMA (GSM) on GSM (CDMA) diffusion is directly proportional to the ratio of CDMA (GSM) subscribers to total potential of GSM (CDMA) subscribers, and is represented by u_{21} (u_{12}) in Eqs. (2) and (3) below. Subtracting the new technology influence $u_{21}\frac{N_2(t)}{\overline{N}_1}$ from the term $(1-\frac{N_1(t)}{\overline{N}_1})$, the logistic competition diffusion model (LCM) (Lotka–Volterra) of GSM and CDMA can be formulated as expressed in Eqs. (2) and (3):

$$\begin{aligned}\frac{dN_1\,(t)}{dt} &= q_1 N_1(t)\left(1 - \frac{N_1(t)}{\overline{N}_1} - u_{21}\frac{N_2\,(t)}{\overline{N}_1}\right) + \varepsilon_1 \\ &= q_1 N_1\,(t) - b_1 N_1{}^2(t) - c_{21} N_1(t).N_2(t) + \varepsilon_1\end{aligned} \tag{2}$$

$$\begin{aligned}\frac{dN_2(t)}{dt} &= q_2 N_2(t)\left(1 - \frac{N_2\,(t)}{\overline{N}_2} - u_{12}\frac{N_1(t)}{\overline{N}_2}\right) + \varepsilon_2 \\ &= q_2 N_2(t) - b_2 N_2{}^2(t) - c_{12} N_1(t).N_2(t) + \varepsilon_2\end{aligned} \tag{3}$$

where $N_1(t)$ is the cumulative GSM subscribers at time t and $N_2(t)$ is the cumulative CDMA subscribers at time t, b_1 and b_2 is the coefficient of technologies own growth (the limitation parameter of the niche capacity related to the niche size for GSM and CDMA respectively), q_1 is the intrinsic rate of growth of GSM, q_2 is the intrinsic rate of growth of CDMA, u_{21} and c_{21} are influence coefficient of GSM on CDMA in LCM, u_{12} and c_{12} are the influence coefficient of GSM on CDMA in LCM, and are the saturation level for GSM and CDMA mobile subscribers respectively, and are the error term (model residual) for GSM and CDMA respectively. The error term is random error term and is known as the residual. It describes the deviation from the model due to factors unaccounted for in the model.

The transformation into a discrete form is necessary to perform the empirical study. To use discrete time data, Eqs. (2) and (3) are converted into the discrete form (Leslie, 1957) as follows:

$$N_1(t) = \frac{\propto_1 N_1(t-1)}{1 + \beta_1 N_1(t-1) + \gamma_1 N_2(t-1)} + \varepsilon_1 \tag{4}$$

$$N_2(t) = \frac{\propto_2 N_2(t-1)}{1+\beta_2 N_2(t-1)+\gamma_2 N_1(t-1)} + \varepsilon_2 \tag{5}$$

where is the growth parameter for technology i and characterizes population growth without competitive influence, characterizes the capacity for technology i, and describes the effect that one technology exerts on the growth rate of the other.

The relation between the coefficients of the LCM, as in Eqs. (2) and (3), and those of the transformed difference Eqs. (4) and (5) were derived by Leslie (1957) as follows:

$$q_i = \ln \propto_i \tag{6}$$

$$b_i = \frac{\beta_i q_i}{\alpha_i - 1} = \frac{\beta_i \ln \alpha_i}{\alpha_i - 1} \tag{7}$$

$$c_{ij} = \gamma_i \frac{b_i}{\beta_i} \tag{8}$$

4.1.3. Gompertz diffusion model: single technology

Gompertz's model assumes that the rate of adoption is a function of the logarithm of the number of potential adopters. The Gompertz diffusion model for single technology is given in Eq. (9)

$$\frac{dN(t)}{dt} = q.\, N(t) - b.N(t).\, \ln N(t) \tag{9}$$

where q is the intrinsic growth rate and b is the deceleration factor. The saturation level for the diffusion process is given by $\overline{N} = e^{q/b}$.

4.1.4. Gompertz diffusion model: multiple technologies

To incorporate the interaction effect of two competing technologies, the Gompertz model is expanded into the Gompertz competition model (GCM) (Kar, 2004) and is given in Eqs. (10) and (11).

$$\frac{dN_1(t)}{dt} = q_1 N_1(t) - b_1 N_1(t).\ln N_1(t) - d_{21} N_1(t).\ln N_2(t) + \varepsilon_1 \tag{10}$$

$$\frac{dN_2(t)}{dt} = q_2 N_2(t) - b_2 N_2(t).\ln N_2(t) - d_{12} N_2(t).\ln N_1(t) + \varepsilon_2 \tag{11}$$

The discrete form of the GCM Eqs. (10) and (11) can be written as given in Eqs. (12) and (13).

$$N_1(t) = N_1(t-1).\, e^{(q_1 - b_1 \ln N_1(t-1) - d_{21} \ln N_2(t-1))} + \varepsilon_1 \tag{12}$$

$$N_2(t) = N_2(t-1).\, e^{(q_2 - b_2 \ln N_2(t-1) - d_{12} \ln N_1(t-1))} + \varepsilon_2 \tag{13}$$

where $N_1(t)$ is the cumulative GSM subscribers at time t and $N_2(t)$ is the cumulative CDMA subscribers at time t, b_1 and b_2 are the limitation parameter of the niche capacity related to niche size of GSM and CDMA technology respectively, is the influence coefficient of CDMA on GSM in GCM, is the influence coefficient of GSM on CDMA in GCM is the intrinsic rate of growth of GSM, is the intrinsic rate of growth of CDMA, and are the saturation limit for GSM and CDMA mobile subscribers respectively, and are the error term (model residual) for GSM and CDMA respectively.

Modis (1999) identified six types of competitive relationships based on the sign of c_{ij} in LCM (Table 2). Here, we discuss similar relationships based on the sign of d_{ij} in GCM.

Table 2
Types of competitive relationships based on the c_{ij} (or d_{ij}) sign.

c_{ij} (or d_{ij}) sign	Relationship	Explanation
++	Pure competition	Occurs when each species suffers from the other's existence
+−	Predator–prey	Occurs when one species feeds on the other
–	Mutualism	Occurs in the case of symbiosis or a win–win situation
−0	Commensalism	Occurs in a parasitic relationship in which one species benefits from the existence of the other, while the other remains unaffected
+0	Amensalism	Occurs when one species suffers from the existence of the other, which is impervious to what is happening
00	Neutralism	Occurs when there is no interaction whatsoever

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4.2. Input data

Since the introduction of CDMA, quarterly data on cumulative subscribers of the two mobile communication technologies, GSM and CDMA, were collected over a nine-year time period (Dec 2002–Dec 2011) with 36 observations. Data were collected from the annual reports and performance indicator reports of Telecom Regulatory Authority of India (2005, 2011). Number of observations in the current study was found appropriate considering the similar number of observations and parameters in the previous studies (Chiang & Wong, 2011; Kreng & Wang, 2011).

5. Analysis and findings

5.1. Estimation results

The non-linear least squares (NLS) estimation procedure was used to estimate the coefficients. Nonlinear least squares has ability to produce good estimates of the unknown parameters in the model which is nonlinear in nature with relatively small data set and provides better fit, and predictive validity (Srinivasan & Mason, 1986). To demonstrate the fitting performance of the models, parameters of both models were estimated with the quarterly number of subscribers up to March 2011 (33 observations). The root mean square error (RMSE) was used to evaluate the goodness of fit (Hwang et al., 2009). Then the out-of-sample forecasts for next three quarters till December 2011 were compared with the actual quarterly number of subscribers. In addition three one quarter step ahead forecast using recursive forecasting technique was done. Forecasting performance of the models was tested by calculating the Mean Absolute Percentage Error (MAPE) and found MAPE within the acceptable limits (Lewis, 1982; Hwang et al., 2009). Also, Mean Absolute Scaled Error (MASE), based on the in-sample, one-step errors from the naïve method was also calculated (Hyndman & Koehler, 2006). Estimation, fitness, and forecasting performance results are presented in Table 3. The model fit for actual and estimated results, of the two technologies for both LCM and GCM is presented in Fig. 3. Residuals were checked for normality by q–q plot and were found to be normally distributed. The plot of residuals versus lag residuals indicated negligible autocorrelation.

Table 3 shows that the GCM parameters were insignificant and had higher RMSE than the LCM parameters, indicating that the latter was a better model for analyzing competitive effects. In addition MAPE for out-of-sample forecast was found to be smaller in LCM indicating better forecast. Also, MASE was found to be less than one indicating better forecast by LCM for GSM technology (whereas in GCM, MASE was found to be greater than 1) than the average one-step naïve forecast computed in-sample. Results of MASE for CDMA technology for the two models were found to be less than 1. Both the forecasting methods indicated LCM as the robust model for analyzing competitive effects. The influence coefficient of CDMA on GSM technology in both models (c_{21} and d_{21}) was negative, while that of GSM on CDMA technology (c_{21} and d_{12}) was positive. However, the t-statistic of c_{12} and d_{12} in both models indicated that the effect of GSM diffusion on CDMA diffusion was not statistically significant. Therefore, it is reasonable to assume c_{12} and d_{12} as 0. This finding leads to the conclusion that the competitive relationship between GSM and CDMA services may be commensalism. More precisely, the results imply that the number of CDMA subscribers is not influenced by the GSM subscribers, but the number of GSM subscribers increases with an increase in CDMA subscribers.

5.2. Equilibrium analysis

Analyzing the competitive relationship using the LCM model provides information on the equilibrium state and changes in trajectory over time. The equilibrium state can be determined by setting zero growth rates for GSM and CDMA.

$$\frac{dN_1}{dt} = 0 \ and \ \frac{dN_2}{dt} = 0$$

Table 3
Estimation results of the competition diffusion model.

Technology	Logistic competition model (LCM) parameters				Gompertz competition model (GCM) parameters			
	α_i (q_i)	β_i (b_i)	γ_i (c_{ij})	Fitted RMSE and forecasted MAPE (*MASE*)	q_i	b_i	d_{ij}	Fitted RMSE and Forecasted MAPE (*MASE*)
GSM	1.12***	1.12^{E-04}***	-4.36^{E-04}*	3.67	0.179***	0.039**	-0.035*	3.89
Out of sample forecast (year 2011)	(0.111)	(1.05^{E-04})	(-4.12^{E-04})	4.13% (*0.85*)				4.99% *(1.2)*
CDMA	1.24***	2.03^{E-03}**	1.14^{E-06}	1.98	0.488***	0.049	0.038	2.07
Out of sample forecast (year 2011)	(0.217)	(1.82^{E-03})	(1.02^{E-06})	2.63% (*0.82*)				2.65% (*0.83*)

RMSE: root mean square error; MAPE: mean absolute percentage error; MASE: mean absolute scaled error.
*** $p < 0.001$.
** $p < 0.01$.
* $p < 0.1$.

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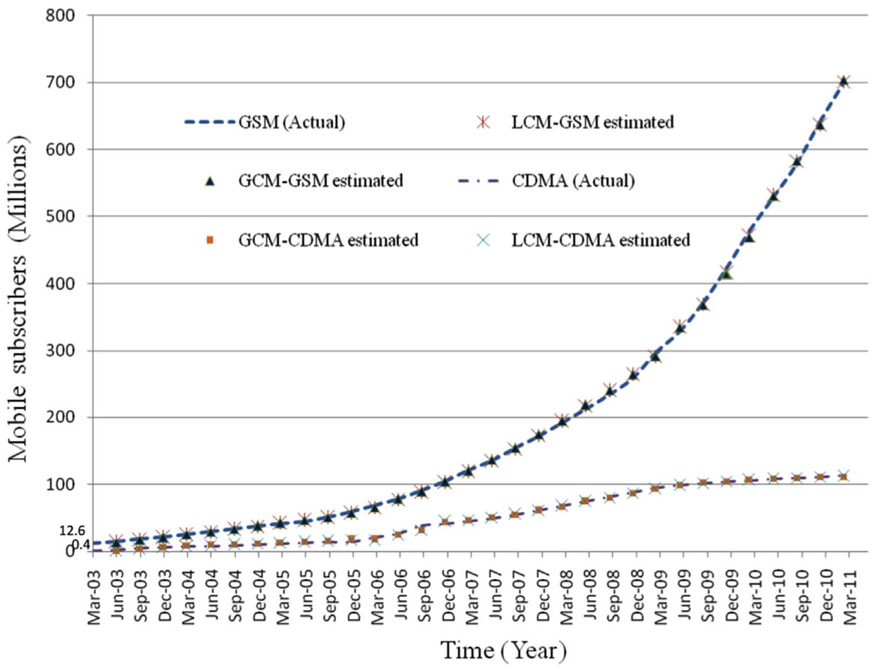

Fig. 3. Actual data and estimated results for the cumulative number of subscribers.

Eqs. (2) and (3) can then be written as follows:

$$N_1 = \frac{q_1 - c_{21}.N_2}{b_1} \text{ and } N_2 = \frac{q_2 - c_{12}.\, N_1}{b_2} \tag{14}$$

In Eq. (14) if $N_1 < \frac{q_1 - c_{21}.N_2}{b_1}$, then the population of species N_1 would increase so that $\frac{dN_1}{dt} > 0$. However, if $N_1 > \frac{q_1 - c_{21}.N_2}{b_1}$, then the population of species N_1 would decrease so that $\frac{dN_1}{dt} < 0$. Similarly, if $N_2 < \frac{q_2 - c_{12}.N_1}{b_2}$, then $\frac{dN_2}{dt} > 0$ and $N_2 > \frac{q_2 - c_{12}.N_1}{b_2}$, then $\frac{dN_2}{dt} < 0$. If the two straight lines expressed in Eq. (14) intersect in the first quadrant, the competing market has an equilibrium point (1560, 118). In Fig. 3, the vertical and horizontal lines represent the equations $N_1 = \frac{q_1 - c_{21}.N_2}{b_1}$ and $N_2 = \frac{q_2 - c_{12}.N_1}{b_2}$, respectively. Fig. 4 shows that the two lines $\frac{dN_1}{dt} = 0$ and $\frac{dN_2}{dt} = 0$ cross each other, indicating the existence of an equilibrium point. The areas with horizontal hatching represent the region in which the number of GSM subscribers will increase ($\frac{dN_1}{dt} > 0$), while the areas marked with vertical hatching represent the region in which the number of CDMA subscribers will increase ($\frac{dN_1}{dt} > 0$). The area with the checks denotes the space where the number of subscribers of both services is expected to increase. The number of subscribers of both services is expected to decrease in the empty space. In this case, however, when the subscribers of the two technologies exist between the isoclines, their joint trajectories always head toward the intersection. Rather than outcompeting one another, the two technologies are able to coexist at this stable equilibrium point, which can change according to the associated dynamics.

The above analysis reveals that mobile telephony in India has an equilibrium point and displays stable characteristics in response to the dynamic changes in the market. As of December 2011, the number of GSM subscribers was 639.64 million and the number of CDMA subscribers was 107 million. These numbers correspond to a point in the checkered area, indicating that Indian mobile telephony has not yet reached the equilibrium point (1560, 118) and that the markets for both services will continue to expand.

6. Discussions

Our analysis of intragenerational technology competition showed that the intrinsic growth rate of CDMA technology (0.217) was greater than that of GSM technology (0.111). This result indicates that the diffusion of CDMA technology has been more rapid than that of GSM. CDMA service providers touched the 50-million-subscriber mark after four years of CDMA launch, whereas GSM operators needed more than 10 years to reach this target. The potential reasons for this variation in diffusion speed include the following:

i. Technological awareness and knowledge: Existing GSM technology raised people's awareness and knowledge of mobile telephony and its common features, which served as a ready base for CDMA technology.

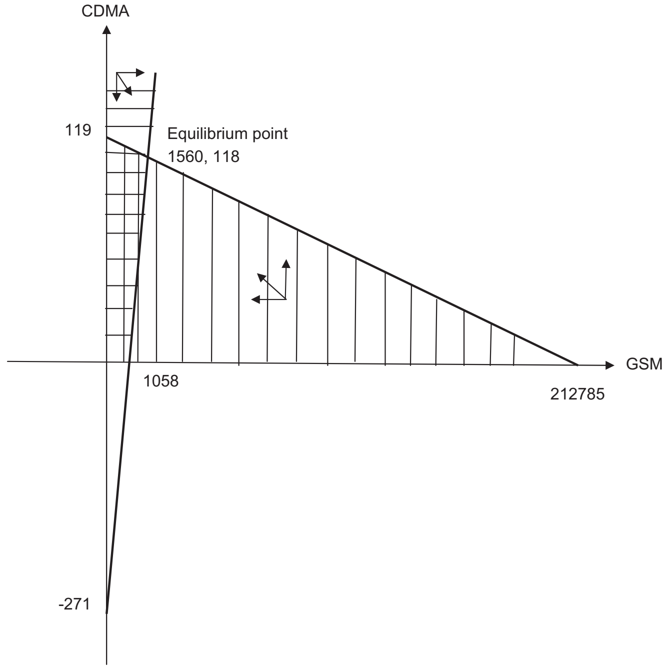

Fig. 4. Equilibrium point of the mobile telephony market in India.

ii. Network expansion: CDMA networks expanded rapidly into the untapped areas of India to deliver voice and data service.
iii. Product and service innovations: CDMA service providers differentiated themselves by bundling services, as in Western countries (handset+connection). This coincided with the launch of ultra-low-cost handsets (CDMA Development Group, 2007), which led to affordable and attractive service connection packages (One Nation, One Tariff). Information about these innovations and their affordability spread quickly, leading to faster diffusion of CDMA technology.

However, despite product and service innovations and faster diffusion, the market share of the CDMA service has not yet exceeded that of GSM. This can be explained by the sign of the influence coefficients of the two technologies. The sign of c_{21} is negative, which indicates that CDMA played a role in slowing down GSM's retardation. That is, although CDMA targeted new population pockets with its expanded networks and mobile connectivity, the influence coefficient c_{21} compensated for its higher diffusion speed, helping GSM enjoy long-term sustainable subscriber growth.

The sign of $c_{12,}$ the influence coefficient of GSM on CDMA, is positive but statistically insignificant. This finding indicates that the diffusion of CDMA technology has remained unaffected by the diffusion of GSM and confirms that GSM technology continues to enjoy the first-mover advantage in mobile communication technologies.

The different signs of the influence coefficients can be attributed to the unique characteristics of the Indian telecom market. For instance, GSM subscribers have the flexibility to change or upgrade their handsets, whereas CDMA subscribers have to use pre-locked handsets (as in Western countries) given by the service provider, which limits the choices of the adopter. Once such limitations are removed, the popularity of CDMA technology may surge. Because of the incumbent nature of GSM, it will continue to be the dominant technology until a major breakthrough occurs. Thus, it can be concluded that the existence of the two technologies has boosted the diffusion of mobile telephony in India. This evidence contradicts reports in the literature that suggest that the presence of multiple technologies impedes the diffusion process.

7. Policy implications

The results of this study indicate that intragenerational technology competition do exist and characterize the diffusion of mobile telephony in India. The growth trend of the two mobile technology diffusion differs and is influenced by the co-existing technology adoptions. This shows that each mobile telephony adopter have different ways of fulfilling their needs, which could result in a different number of adoptions for the two technologies. Mobile service providers of the competing technologies should also focus on understanding the nature of additional subscriptions, i.e. the purpose, the nature of use, the type of subscriptions: private or business; prepaid or postpaid; data or voice, the features and the price of handset. Moreover, CDMA market can be enhanced by increasing fitness to adopter needs, and developing and integrating new features and functions.

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The study reveals that both GSM and CDMA markets will continue to expand with greater expansion of GSM technology. The finding suggests that continual investments in both the mobile technologies may drive an operator's success and the economic growth of the nation. For the regulator and policy makers, having an early prediction of the growth trend and equilibrium point for a certain technology enables them to anticipate and design strategies for spectrum re-allocation and other resources. The findings suggest that policy makers should support the presence of multiple competing technologies providing similar service within a technological generation to speed up the diffusion of new upcoming services.

8. Conclusions

This study analyzed the interactions between the diffusion of two mobile technologies in India—GSM and CDMA—using the two epidemic diffusion models. The Gompertz model is often used to model technological substitution that is intensely controlled by the wearout of units of the old technology whereas logistic model models substitution based on the advantage of new technology. The two models were extended to incorporate competition effects and to identify the diffusion pattern of the two technologies. We found that LCM explains the diffusion of two technologies and their interaction better than GCM both in terms of historical pattern and forecasting capability. The result indicates the use of LCM when analyzing similar technology in competitive environment like Indian Telecommunications. The model gave us insights into the current competitive relationship between GSM and CDMA technologies which shared the same market. It also provided information on the survival or extinction of each technology, due to the competition effects and the market at the equilibrium.

The introduction of the new technology (CDMA) within a generation in the market is believed to be one of the most significant contributor to the diffusion of mobile telephony in India. The results suggest that the rate of diffusion of CDMA was faster than that of GSM in India. In particular, the launch of CDMA made mobile telephony more affordable to the Indian masses. However, GSM continues to dominate the diffusion process owing to its early lead. As such, it can be concluded that innovative ideas and customer-friendly pricing strategies are required to expedite the diffusion of mobile technology and maintain its competitive nature. Technological innovations like the introduction of new services and products may lead to changes in the marketplace, resulting in less or even no competition. In any case, long-term forecasts should be cautiously made, and we recommend that further studies be conducted using updated datasets with more observations. The future research can be done to extend the competition models to incorporate factors such as pricing, advertising, and regulation arrangements. The models presented in this paper can be applied to similar and other communication services in different countries that have competitive markets.

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