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Diffusion of Mobile Telephony Services in India

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Abstract: ***Various factors have led to the emergence of India as the second largest mobile telephony market in the world. In terms of growth velocity, India's mobile telephony diffusion exhibits three distinct growth phases viz: exponential growth phase, linear high growth phase and linear slow growth phase. This paper describes these phases for growth of mobile telephony in India during 1996-2019 and further attempts to model the diffusion using standard epidemic models like Gompertz, Logistics and Bass Models to examine if they provide a good fit. Assuming that there shall not be any unusually high level of change in the causal variables- saturation tele-density has also been predicted using these models. As a part of a larger study on pricing imperatives of evolving mobile telephony in India, this study strives to add and update the available literature on mobile telephony diffusion in India. It also evaluates the impact of some of the key determinants of mobile diffusion globally on Indian growth story viz: digital divide (between rural and urban areas), per capita Gross Domestic Product, technological evolution; and substitutes like fixed telephones.***

Keywords ***: Tele-density, diffusion, Bass Model, Gompertz Model, Logistics Model, GDP, Mobile Telephony.***

I. INTRODUCTION

Subsequent to phenomenal growth of mobile telephony services in last two decades, with 1165.46 million wireless telephony subscribers (in June 2019) - India is the second largest wireless telecom market in the world- ahead of USA and next only to China. The diffusion of mobile telephony services in India is an interesting study- not only because of the sheer magnitude of the market but also because of the diversity in adoption rates across time and geography. The country's overall mobile phone penetration of 90.11 (in June 2019) comprised of a very wide range tele densities- from 240.53 in Delhi Circle to a mere 60.13 in Bihar & Jharkhand Circle. Similarly, mobile penetration in rural areas stands at 56.68 only compared to 156.42 in urban areas.

Globally, the mobile diffusion is impacted by demand side variables viz: per capita GDP (or disposable income), diversity of income and other indicators of social & economic growth, adoption level of legacy fixed lines, demographic factors like household size, population density, literacy rate & age profile of users, culture factors & climate; and supply side variables like investments, availability of supporting infrastructure (roads, electricity etc.) , evolution of multiple generations of technology (including enabling prepaid models) & simultaneous presence of two technologies (GSM & CDMA), spectrum availability, permission to erect towers, availability of low cost hand-sets, government regulations etc. It will be reasonable to hypothesize that competitive intensity and service pricing also impacts the adoption level. This paper studies the general diffusion pattern and strives to evaluate the effect of some of the aforesaid variables likely to impact the diffusion of mobile telephony in India.

II. METHODOLOGY

In this study, mobile subscription and tele-density data have been, in general, taken from periodic reports published by Telecom Regulatory Authority of India (TRAI). Wherever required, these data have been validated from reports of service provider associations like Cellular Operators Association of India (COAI) and Association of Unified Service Providers of India (AUSPI). These numbers are, in turn, based on the data reported by the operators to their association and the regulatory authority. GDP data has been taken from the publication of Ministry of Statistics & Programme Implementation of Govt. of India and NITI Aayog publications. Population & population density has either been taken from census of India data or are derived from the published NITI Aayog and TRAI data used in this study.

A literature review has been done initially to understand the various parameters likely to impact the mobile telephony diffusion pattern in India. Subsequently, assuming no abnormal change in the impacting variables- a saturation tele-density is predicted by fitting in the Indian wireless telephony growth trajectory some with the commonly used diffusion models in case of innovation and technology. An analysis of individual impact of some of the possible causal factors enumerated earlier on the diffusion of mobile telephony is also separately done to understand their role on the overall diffusion pattern and has been presented in subsequent sections here.

III. LITERATURE REVIEW

Sutherland (2009) has commented on the issue of growth in the sector being considered in terms of the number of subscribers and the inherent anomalies in the subscriber count methodologies.

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He has specifically mentioned issues regarding duplication of subscriber count and questioned the logic of 100+ tele-density in various areas. He goes on to point out significant variations in the operator reported mobile tele-density and the actual tele-density detected through Surveys in various European countries. As per his studies, the per capita GDP and tele-density scattergrams drawn based on operator data and Survey data reveal different patterns. Sutherland has, accordingly, concluded that operator reported customer numbers are not correct, in general and should not be considered as a measure of success of public policy, in particular. He adds that to determine the public policy, data from independent surveys should be relied upon including that of population without mobile phone and those having multiple mobile phones. Sutherland's observations, while made in context of Europe and South Africa are apparently extremely valid in Indian context as well where a reduction in the subscriber number has been reported in the past with increasing proportion of the reported subscriber base as active wireless subscribers on the date of peak registrations on Visitor Location Register (VLR) peak subscriber percentage.

The discussions on significant non ownership of mobiles despite an extremely high tele-density has linkages not only with the huge inequalities of income but also with the appropriation of mobile telephony by the low income group population. While there are indications of high levels of appropriation amongst people involved in non-agricultural professions in urban areas, of washer-men, grocery shops, rikshaw pullers, daily wage labourers, domestic maid servants etc. in urban areas, a detailed study of their adaption in rural households in various states may be required to determine the exact status. Dey, Binsardi, Prendergast & Saren (2013) have analysed this in case of bottom of pyramid (BOP) customers' – marginal farmers of Bangladesh. Dey et al have used concentrated ethnographic immersion for their study along with methodical and investigator triangulation in the villages of Bangladesh for four months. They have concluded the need of new product development (NPD) to take care of specific needs of the illiterate (e.g.: touch screen, better audio-visual interfaces), knowledge specific to farming (e.g.: pesticides, seeds, farming technology, prices of the produce) and the entertainment needs of villagers in local language. The technology will, thus be more inclusive leading to better penetration of mobile phones in an altogether new consumer segment which is not essentially averse to adapting to new technology. Various Indian villages- particularly in the east and north east are very similar to the villages in Bangladesh in income levels, culture as well as lifestyle habits and the study by Dey et al is extremely relevant even in Indian context. This is more pertinent because despite continuous increase in the subscriber numbers till date- the digital divide viz: the tele-density gap between rural and urban areas has been increasing till Dec 2011 and has been subsequently hovering around 100% (Fig. 6)

Sridhar (2006) has used constant rate exponential model as well as internal influence based logistic model for forecasting subscriber base. He has concluded that while in early stages of service diffusion, the forecasts are reasonably accurate- they also stated the requirement of making the model more comprehensive by including external factors affecting the growth so that the prediction accuracy is conserved during later stages of growth also.

Singh (2008) also presented the diffusion of mobile telephony services in India between 1995-96 to 2005-06 using the S-curve hypothesis and has tried to forecast the mobile density in future years. He has used Gompertz model besides the Logistic model and concluded that although both these epidemic models can capture Network Externalities the former is more suitable in case of mobile telephony in India. It is worthwhile to point out here that Meade & Islam (1995) have shown that the model providing best fit to historical data may not necessarily be the best model in terms of forecasting accuracy. Singh's study deals with mobile subscriber numbers at an aggregate level without considering the factors influencing individual purchase decisions. His models have not included such demand determinants- which may be possible reasons of significant deviation, in realty from his forecasts. Singh's analysis concluded that inflection point would occur between 2011 to 2013 with mobile density ~45. He predicted a mobile density of 71 during 2015-16 and 100+ by 2022-23. The actual growth data, however reveal that maximum growth rate was achieved in March 2006 and that the mobile density touched 71 in April 2011. The mobile density as on March 2019 end is 88.46. This goes on to prove Sridhar's hypothesis that for the diffusion forecast to be accurate during later stages of the growth curve, external factors affecting the growth shall have to be included in the model.

Kumar, Shankar & Momaya (2015) have, however, stated that the diffusion of mobile telephony does not follow a S-curve in all cases. Further, despite its frequent use-Bass diffusion model (BDM) is unable to explain diffusion. They have also pointed out parameter sensitivity of BDM and recommended an integrated diffusion model which also takes care of technological growth, income disparities, de-adoption etc.

James (2010) has used a 2 X 2 matrix (Fig. 1) to classify various countries based on penetration and growth rate of mobile phones for the period 2000 to 2006 and subsequently analyse their performance in closing the digital divide between developed and developing countries. He has used the simple arithmetical conditions to infer that, if Mobile Phone Stock and Growth are depicted by M & G respectively, then

$M_{developed} / M_{developing} > G_{developing} / G_{developed}$ => the absolute digital divide increases

Similarly,

$M_{developed} / M_{developing} < G_{developing} / G_{developed}$ => the absolute digital divide decreases

Considering the tele densities and the growth rates as shown below, it is discovered that the underlying assumption of James is that the growth rates can have positive values only. The aforesaid inequalities should be amended by reversing the equality sign in case, both the growth rates are negative. Similarly, in case only one of the two- either growth rate in developed or the developing countries is negative then the digital gap shall expand or narrow down respectively overriding the inequalities above.

The rural and urban tele densities are very often not strongly correlated with income is explainable by proposition made by Dasgupta et al (2002) stating that while Income is one of the most important variables influencing digital divide, other factors viz: policy reforms as well as income disparities can significantly impact the growth reforms as well as

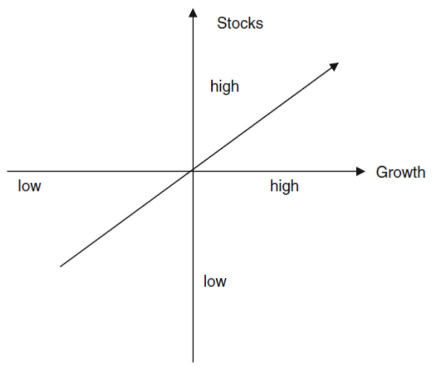

Fig 1. Classification matrix

income disparities can significantly impact the growth behaviour. In fact, there are many articles on the dependency of per capita GDP on tele-density and the reverse. Ahn & Lee (1999), Chris (2003), Chabossom et al (2010), Garbacz &Thompson (2007); and Afridi (2010) have indicated that aggregate mobile demand and penetration is positively correlated to GDP per capita. Kalba (2008) has concluded that correlation of country's income level with mobile adoption level is stronger in emerging markets in comparison to the developed countries. Further, growth in the mobile telephony is expected to have a positive impact on economy, in general-particularly through network effects. A study by London Business School has found that a rise of 10 in tele-density boosts GDP growth by 0.6% (Waverman et al.,2006). Appropriate models exhibiting their relationship should consider this endogeneity. Sridhar & Sridhar (2004) have used Roller & Waverman's (2001) framework to consider this endogeneity. Kathuria, Uppal & Mamta (2009) also show that Indian states with a tele-density threshold of more than 25 will grow faster on account of growth amplification by network effects.

Rego & Kumar (2014) have studied factors influencing diffusion of mobile telephony in rural India and stated that there is a correlation between electricity access, other economic indicators of quality of life as well as the time span since these indicators viz: bicycle, TV, tractor etc. are being used. The study of Rego & Kumar is in line with Rogers' (1995) theory of innovation diffusion which explains the diffusion process via different channels in different social systems over a period rather than mere economic matrices. This study, in a way-explains partially as to why the correlation between Per capita income and tele-density in India is not very strong.

Saripalle & Mukhopadhyay (2016) studied a panel data of 18 major states for the period 2002-2012. While cautioning for some endogeneity in their model, they have stated that income and inequality of income, both have significant impact on diffusion of mobile telephony. According to their study, 1% increase in GDP may increase the mobile ownership by up to 5%. However, while 1% increase in urban inequality is likely to increase mobile phone adoption by 1.1%, a similar increase in rural inequality is likely to marginally decrease mobile phone adoption. Saripalle & Mukhopadhyay also determined that while states with higher population tele-density have higher existing tele densities but growth in tele-density is negatively related with population density. Their study also negates any impact of literacy and age profile on the mobile telephony growth rate.

Chakravorty (2007) studied the diffusion of mobile telephones in the period 1993-2004 in Asia. He has indicated that time elapsed since entry as well as degree of competition play a significant role in accelerating the diffusion of mobile telephony. In fact, Gruber (2001) has also concluded that the diffusion speed increases with increase in number of service providers.

Chakravarty (2007) has stated that the capacity of fixed line telephony has a positive impact on the diffusion of mobile telephony on account of the increased network size implying a relation of complementarity between the two services. Ahn & Lee (1999), Hwang et al (2009), Garbacz & Thompson (2005) and Gruber (2001), in their studies had also found a positive relationship between the two. On the contrary, Sung and Lee (2002), based on their study of the growth of fixed and mobile subscriptions for 1991-98 for six Korean provinces and concluded that every percent of increase in mobile lines results in 0.14% to 0.22% fixed line disconnections clearly indicating a substitution effect. Madden and Coble-Neal (2004) have also agreed with this assertion based on study of telecom demand in 56 countries during 1995-2000. Rodini et al (2002) , based on his study of Markets in United States of America as well as Okada & Keiko (1999) base on his study of Japanese market Cadima & Barros (2001) based on a study in Portugal; Gruber & Verboven (2001) for EU; and Dzieciolowski & Galbraith (2004) for Canada have also arrived at similar "substitution effect" result . In view of vast difference in results- it would be appropriate to infer that this relationship is dependent on prevailing fixed line tele-density, tariff structure and general behaviour of the people and hence country or market specific. Cadima and Barros (2000) concluded after their study of the diffusion of Portuguese telephony market that mobile telephone adoption slowed fixed-line growth, but fixed-line subscription growth had no impact on mobile phone diffusion. Hamilton (2003) found that the relationship is quite complex and even in markets with low fixed line network access – the two services sometimes behave as a substitute while on others, they exhibit complementarity. He concluded that in low fixed line penetration areas (e.g.- developing countries)-mobile services are substitutes. Indian experience also appears to be aligned with the same as the growth of mobile telephones in India has further pushed downwards the already low fixed lines (Fig 19)

Most of the diffusion studies (Botelho & Pinto, 2004; Chaddha & Chitgopekar, 1971; Gamboa & Otero 2009; Michalakelis, Varoutas, & Sphicopoulos, 2008; Singh, 2008) have not considered availability of two or more technologies competing for the same service. In view of the existence of two technologies-

CDMA &GSM- to consider their interplay, Gupta & Jain (2016) have considered Gompertz Competition Model (GCM) and Logistic Competition Diffusion Model (LCM) instead of Gompertz and Logistic diffusion models respectively in their study. The logistic diffusion model is characterized by

$$dN(t)/dt \;\alpha\; N(t) \qquad (1)$$

$$dN(t)/dt \;\alpha\; [\,Nsat - N(t)] \qquad (2)$$

Equations (1) and (2) are combined to give

$$dN(t)/dt = q.\ N(t).\ [1- N(t)/Nsat] + \varepsilon 1 \qquad (3)$$

The equation (3) above in case of two competing technologies, in the LCM gets converted to equations (4) & (5) below

$$dN_1(t)/dt = q_1.N_1(t)[1-N_1(t)/N_{1sat} - u_{21}.N_2(t)/N_{1sat}] + \varepsilon_1 \qquad (4)$$

$$dN_2(t)/dt = q_2.N_2(t)[1-N_2(t)/N_{2sat} - u_{12}.N_1(t)/N_{2sat}] + \varepsilon_2 \qquad (5)$$

To facilitate use of discrete time data, the aforesaid equations have been converted into discrete form (Leslie (1957)) as under:

$$N_1(t) = \frac{\alpha_1.N_1(t-1)}{1+ \beta_1 N_1(t-1) + \gamma_1 N_2(t-1)} + \varepsilon_1 \qquad (6)$$

and

$$N_2(t) = \frac{\alpha_2.\ N_2(t-1)}{1+ \beta_2 N_2(t-1) + \gamma_2 N1(t-1)} + \varepsilon_2 \qquad (7)$$

N(t) and N (t-1) denote cumulative subscriber number at time t and t-1 respectively. Subscript 1 & 2, in our case may denote GSM and CDMA respectively. α_i, β_i and γ_i are transformed parameters given by:

$q_i = \ln \alpha_i$, $b_i = \beta_1 q_i /(\alpha_i-1)$; and $c_i = \gamma_i b_i / \beta_1$

In the above, b_i = coefficient of own growth of technology i, q_i = intrinsic rate of growth of technology i, c_{ij} = influence coefficient of technology i on j, and ε is residual. Similar treatment in Gompertz Competition Model (Kar, 2004) gives the following result with usual notations-

$$N_1(t) = N_1(t-1).\ e^{q_1-b_1\ln N_1(t-1) - d_{21} \ln N_2(t-1)} + \varepsilon \qquad (8)$$

$$N_2(t) = N_2(t-1).\ e^{q_2-b_2\ln N_2(t-1) - d_{12} \ln N_1(t-1)} + \varepsilon \qquad (9)$$

In fact, Modis (1999) have further classified competitive relationship based on the value of c_{ij} and d_{ij} above as pure competition, predator-prey, mutualism, commensalism, amensalism and naturalism.

Gupta & Jain (2016) had however, forecasted an equilibrium point of (GSM=1560, CDMA=118) based on their studies while, we know that CDMA had reached ~0 by September 2018 due to other factors which were not a part of their study. More recently, Jha & Saha (2018) have come up with a study of diffusion of 2G to 4G in UK, France, Germany & Italy using Bass, Gompertz and Logistic growth models. They have concluded that Bass model was found to be more suitable to explain 2G diffusion while Gompertz and Logistic models are suitable for 3G & 4G diffusion. Bhushan (2012) has endeavoured to cover entire 'supply line" of telecom diffusion by trying to use several variables (like Revenue, Profitability, Subscription demand, Rate of Adoption, R &D, Infrastructure availability etc.) classified into three subgroups- under Supply side dynamics, Adoption dynamics and Market size dynamics. Bhushan has also done sensitivity analysis and simulations through scenario projection of multi usage situation.

Kalba (2008) has also shown through his study of multiple markets globally that while the number of mobile telephony service providers has a distinct positive effect in accelerating diffusion, the impact is substantially reduced as the number of operators in a geography goes beyond three or four.

IV. SUBSCRIBER GROWTH

Subscriber, for the purposes of this paper, represents a Subscriber Identity Module (SIM) or mobile number reported to be active by the operators. Accordingly, SIMs used exclusively for data usage are also considered as a subscriber and multiple numbers being used by same person is counted multiple times. This definition is more a matter of convenience as the Indian telecom regulatory body reports the numbers likewise.

With a large majority of subscribers on prepaid model and a significant part thereof with SIMs having lifetime validity- elimination of inactive SIMs is a difficult task. The authenticity of the published subscriber numbers becomes fuzzy also because elimination of dormant prepaid SIMs from the records is a thankless job within the operator organizations and hence, does not receive adequate attention. Accordingly, any subscriber number data reported by operators themselves may have a systemic bias of being on the higher side. There may even be a tendency to inflate subscriber numbers in different geography to showcase service roll out conditions mentioned in the license.

Additionally, reported tele-density of 235.65 in Delhi and 146.5 in Himachal Pradesh need to be further explored in terms of multiple SIM ownership and non-ownerships to effectively understand the diffusion of mobile telephony. Another point to be pondered upon is whether the number of subscribers are willingly inflated and Whether the delay in removal of dormant numbers from the list is intentional to exhibit lower ARPUs and to claim Govt. Subsidies or tax concessions. The reported Subscriber numbers across last few years, VLR %age and active subscribers on the date of peak VLR in a month for India are shown in Figure-2(a) &2(b). It may be noted that the slow pace of subscriber growth or reduction in subscriber numbers in the recent past is partly because of 'number cleansing'- viz: removal of dormant accounts – as is seen by increased VLR %age in recent times. Number of subscribers active on the date of peak VLR in a month, accordingly may be considered as a better indicator of actual subscribers. It is noted that while maximum reported subscriber number till date was 1186.84 million in June-2017 but maximum active subscribers of 1031.28 million were reported in November-2018.The monthly peak VLR% had gradually moved from 72.37% in March-2012 to 90.6% in March-16. However, in view of the turbulence caused due to the closure of various operator companies and the consolidation in the sector subsequently- weeding out inactive subscriptions may not have happened much as the peak VLR% has come down to 84.41% in June 2019.

A. Subscriber Numbers

The exceptional growth journey of mobile telephony in India, can be categorized, in terms of three different growth phases as under:

(i) Exponential Growth Phase (1999-2006)
(ii) Linear (High growth) Phase (2006-2013)
(iii) Linear (Slow Growth) Phase (2013-till date)

The number of mobile telephony subscribers has grown from 1.2 million in March 1999 to 1161.81

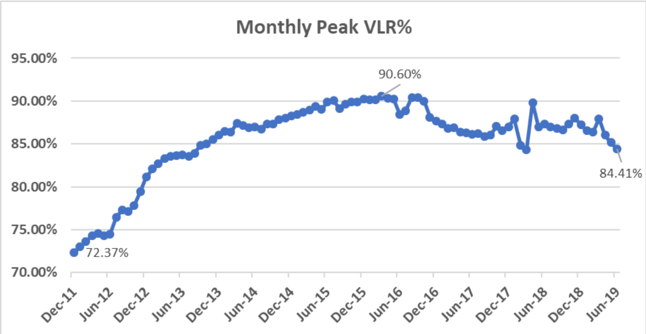

Fig.2(a). Reported peak VLR% of wireless subscriber in a month

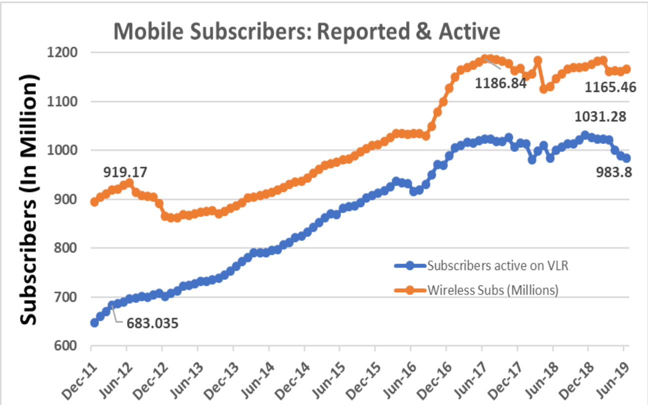

Fig. 2(b). Reported Subscribers vs. number of subscribers reported to be active on the day of peal VLR in a month.

million in March 2019 in the last twenty years (Figure 3(a)). Except a decline in FYE March 2013 & FYE 2019 because of closure of various service provider companies and other market related reasons, the subscriber numbers have been consistently growing, although with a declining growth rate. The plot of Subscriber CAGR from 2000 onwards (calculated on the subscriber numbers of 1999) clearly shows this trend, which is not different from what is generally expected as we move towards saturation tele-density (Figure 3(b)).

It is observed that while the period 1999-2006 exhibited a truly exponential subscriber growth (Fig: 4(a)), the growth rate declined subsequently. Accordingly, in the period 2006-13- the growth rate is high(Fig: 4(b)), but it is linear instead of exponential. In post 2013 phase, due to a variety of reasons, the slope of this linear growth curve has also reduced significantly (Fig, 4 (c))

B. Diffusion Models

The absorption of any new successful technology or innovation, due to its cumulative nature, usually follows a Sigmoid Curve. The most prevalent S-curves models are Bass model proposed by Bass (1969), Logistic family models propose by Bewlwy & Fiebig (1988) and Gompertz model (Gompertz (1825) , Rai (1999)) . This historical data has been fitted by using the OLS estimation and by maximizing the coefficient of determination rather than other regression methods as the same is found to have better predictive capacity and the saturation tele-density so determined appear to be more realistic.

1. Gompertz Model

To eliminate the impact of the growing population on the

Table 1: Characteristics of mobile telephony market in different growth phases

	1999-2006	2006-13	2013 onwards
Demand & Supply	Limited Installed service capacity	Service capacity commensurate with demand	Service capacity higher than demand
No. of Service Providers	Limited No. of Operators in a Circle (No.≤3)	Increased Competition. No. of Operators ~ 4 to 8 in a circle	Hyper competition- average ~8 operators per circle reduced to 4 in March 2019 post consolidation 4 .
Beginning of Period Wireless Subscriber No.	1.2 Mn	101.86 Mn	867.80 Mn
End of Period Wireless Subscriber No.	101.86 Mn	867.80 Mn	1165.47 Mn as on 30th June 2019
End of Period Active Wireless Subscriber No.	NA	722.96 Mn	983.8 Mn as on 30th June 2019
Average annual Subscriber growth rate for the period	88.6% CAGR	35.81% CAGR	4.83% CAGR till June 2019
Average annual Subscriber growth rate based on Active Subscriptions	NA	NA	5.05% CAGR till June 2019

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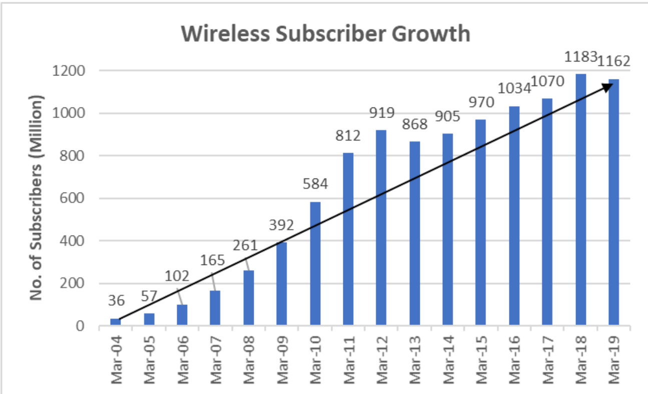

Fig. 3(a). Wireless Subscriber growth in last 15 years

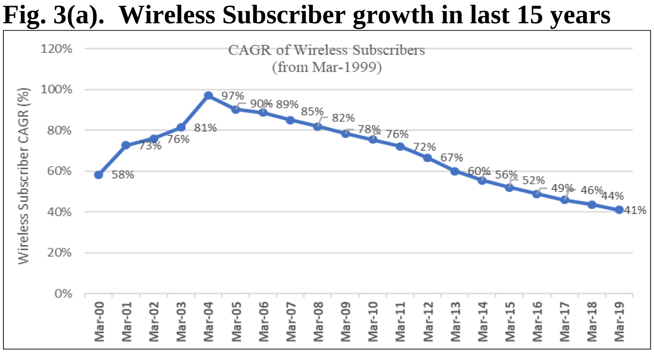

Fig. 3(b). CAGR calculated vis a vis March 1999 wireless subscriber numbers

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growth, tele-density has been taken as variable under study rather than the gross subscriber base. Tele-density is defined as number of subscriptions or SIMs per 100 people.
Gompertz model is shown in

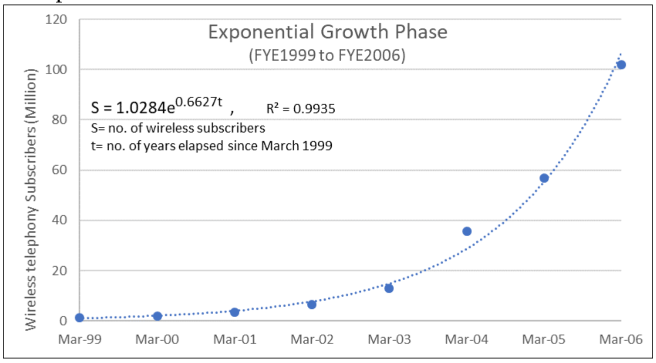

Fig. 4(a).Wireless Subscribers- exponential growth during 1999-2006.

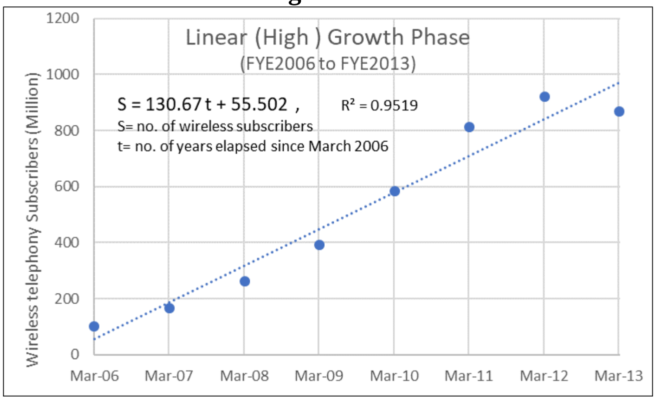

Fig. 4(b). Wireless Subscriber growth in the period 2006-13.

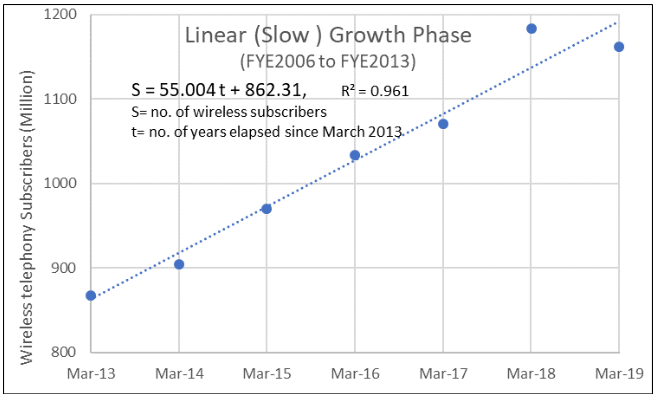

Fig. 4(c).Wireless Subscriber growth from 2013 onwards

Fig.5(a) and is represented by the following equation:

$$D(t) = S + e^{-be^{-ct}} + e_t \quad (10)$$

D(t) = Mobile tele-density at period t
t = value assigned to time at period t (years elapsed since March 1996, in this case); et = error term; S is saturation level and all parameters S, b and c are positive.

If we try to fit in this curve to the mobile telephony subscription data up to March 2019- we get the following curve:

$$D(t) = 88.173e^{-0.421e^{-198.73t}} + e_t \quad (11)$$

This implies that the Gompertz Model suggests that the saturation tele-density is 88.173. Not surprisingly, even after reaching a tele-density of 91.09, the tele-density is back at 88.46. If we consider maximum number of the active subscribers registered on the Visitor Location register (VLR), this number may reduce to 77.79 signifying a residual growth potential. In fact, the model gives inflection point at ti given by the following:

$t_i = \ln(b)/c$; (12)

and the maximum growth rate (μm) is achieved at this point, given by

$\mu_m = S.c/e$ (13)

In our study, inflection point should be found at ti = 12.57 (in oct-Nov 2008) where μm= 1.138 per month. This is quite close with actual observed growth and inflection points thereby partially validating the model.

Further, we test the following hypothesis

Null hypothesis H_0: The wireless tele-density in India (D(t)) does not follow the Gompertz growth model with respect to the time period (t) since launch of mobile telephony services.

Alternative hypothesis H_1: The wireless tele-density in India (D(t)) follows the Gompertz growth model with respect to time period (t) since launch of mobile telephony services, and (D(t)) and t are accordingly significantly related.

Using the two-tail student - t test for the same, the t statistic value obtained =45.86 which is higher than t critical= 3.819 obtained for a degree of freedom = 21 and level of significance=0.001. Hence at 99.9% confidence level, the null hypothesis is rejected, and it can be concluded that the wireless telephony diffusion is following the Gompertz curve with parameters calculated as above.

2. Logistic Model

With similar notations, the logistic model is typically of the following form:

$$D(t) = \frac{S}{1 + be^{-ct}} + e_t \quad (14)$$

Based on year-end data of tele-density available, the logistic model gets the best fit at S=86.631, b =2776.642 and c=0.585, thereby yielding the following:

$$D(t) = \frac{86.631}{1 + 2776.642\ e^{-0.585t}} + e_t \quad (15)$$

Clearly, logistic model indicates to a saturation tele-density of 86.631. This is shown in Fig. 5(b). Again, we test the following hypothesis

Null hypothesis H_0: The wireless tele-density in India (D(t)) does not follow the simple logistic growth model with respect to the time period (t) since launch of mobile telephony services.

Alternative hypothesis H_1: The wireless tele-density in India (D(t)) follows the simple logistic growth model with respect to time period (t) since launch of mobile telephony services, and D(t) and t are accordingly significantly related.

Using the two-tail student - t test for the same, the t statistic value obtained =45.599 which is higher than t critical= 3.819 obtained for a degree of freedom = 21 and level of significance=0.001. Hence at 99.9% confidence level, the null hypothesis is rejected, and it can be concluded that the wireless telephony diffusion is following the logistic curve with parameters calculated as above.

3. Bass Model

Bass model can be written in the following form:

$$D(t) = D_{t-1} + \left(\gamma + \frac{\beta D_{t-1}}{S}\right)(S - D_{t-1}) + \varepsilon_t \quad (16)$$

Our fitment to the actual data yields Saturation tele-density S=85.477, gives Innovation coefficient γ =0.006 and Imitation

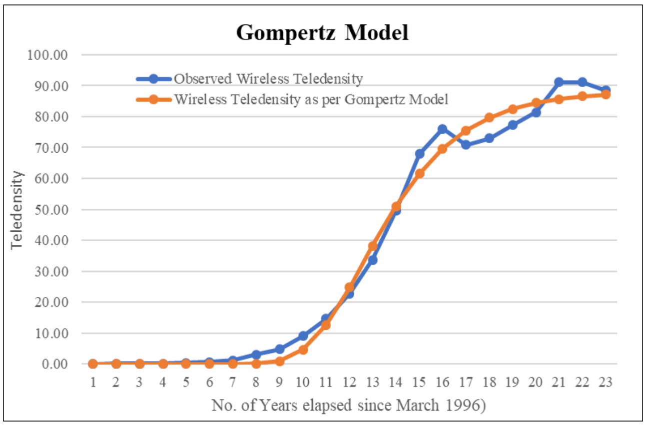

Fig. 5(a). Gompertz Model for Indian Mobile Subscriber growth from 1996 onwards

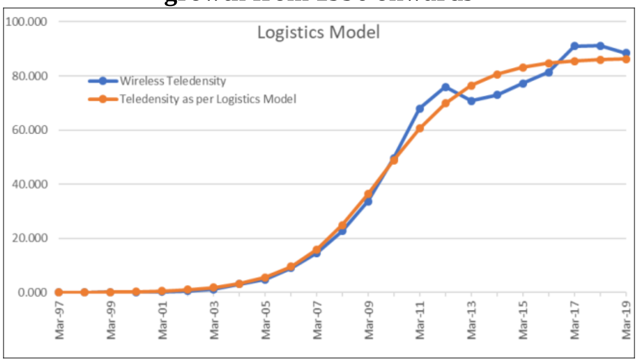

Fig. 5(b). Logistic Model for Indian Mobile Subscriber growth from 1996 onwards

coefficient β=0.6120 thereby giving the following result:

$$D(t) = D_{t-1} + \left(0.006 + \frac{0.6120\, D_{t-1}}{85.477}\right)(85.477 - D_{t-1}) + \varepsilon_t \quad (17)$$

Bass model is shown in Fig: 5(c). It can also be shown as a good fit as calculated t of 29.290 is higher than t critical= 3.819 obtained for a degree of freedom = 21 and level of significance=0.001.

In terms of predictive values, Logistics model appears to be the best having least MAPE. However, the higher MAPE of Gompertz model is because of errors in the initial phase when the predicted growth is sluggish. The predicted values for last 10 years show almost identical deviations from the observed value for Gompertz and Logistics models. A comparison of various parameters denoting goodness of fit for the various models is shown in table 2.

4.3 <u>Digital Divide</u>

Besides a moderately high subscriber growth rate, other distinct characteristic exhibited by the sector is glaring rural-urban divide with rural tele- density of merely 56.99% compared to urban tele-density of 160.78% as on June 2019 end. (Figure 6(a) & 6(b)). The phenomenon of adoption in the initial phase happening in urban areas can be attributed to several factors including higher per capita income, occupational pattern in urban areas, easy availability of supporting infrastructure in urban areas as well as mobile operators' strategy. The arithmetic framework of James (2010) can be easily extended to determine the impact of existing growth over the digital divide between rural and urban areas and to see if the gap is narrowing down. Accordingly, as is seen in the Fig. 6(a)
& 6(b), the digital divide has been expanding till 2012 and

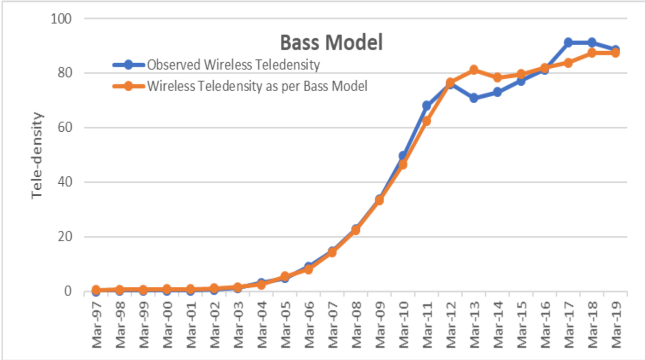

Fig. 5(c). Bass Model for Indian Mobile Subscriber growth from 1996 onwards

Table 2: Summary of three diffusion models considering time since inception and tele-density as the variables under study.

Model	Saturation Tele-density	R^2	Adjusted R^2	Root Mean Square Error (RMSE)	Mean Absolute %age Error (MAPE)
Gompertz	88.17	**0.9901**	**0.9886**	3.6855	0.4434
Logistic	86.63	0.9900	0.9884	3.6372	**0.204**
Bass	85.48	0.9763	0.9725	**3.3152**	0.3096

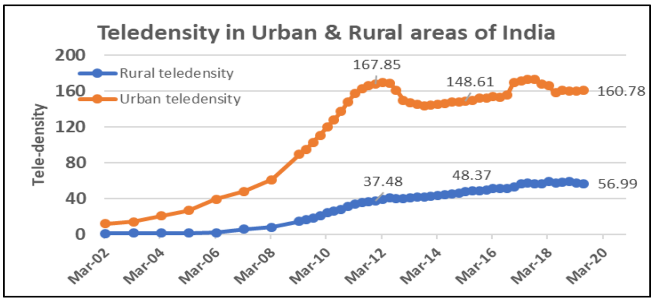

Fig. 6(a). Tele-density growth in urban and rural areas

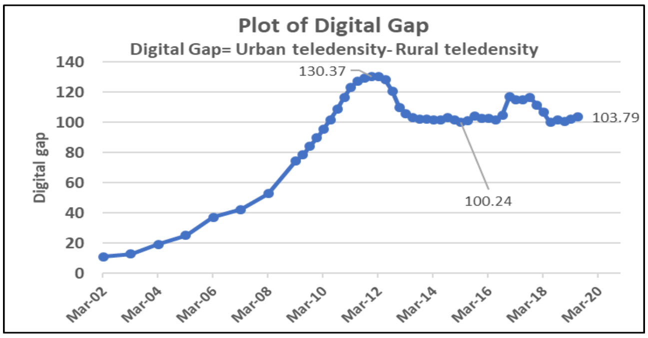

Fig. 6(b).The growing digital gap has declined after achieving a peak in Dec-2011.

subsequently it has been reducing-although with a wavering and slow pace. The

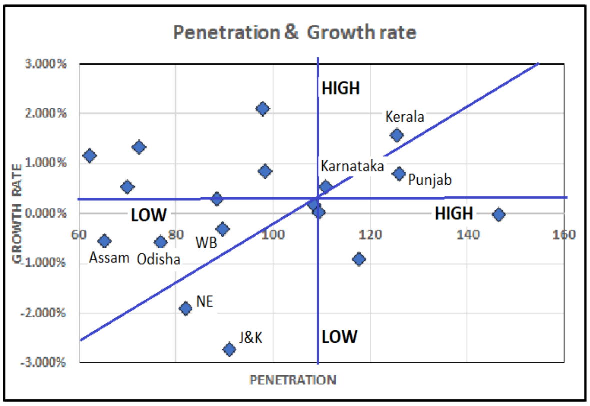

Fig. 7. Delhi (falling in High-Low group) has been ignored for the purpose of aforesaid scattergram to facilitate an enlarged view for other circles. Base numbers for classification as high or low are 110 for Penetration and 0.3% for growth rate

tele-density gap increased up to 130.37 in Dec 2011 but has come down to 103.79 in June 2019.

Instead of various countries used by James, we can use the telecom circles to arrive at a similar classification as under. The High-High & Low-Low Circles are also tabulated separately:

Table 3. High-High & Low-Low telecom Circles

High-High			Low-Low		
State	**Tele-density (Dec'18)**	**Per capita GDP***	**State**	**Tele-density (Dec'18)**	**Per capita GDP***
Punjab	125.98	114561	J&K	90.99	62857
Kerala	125.52	139195	NE	82.01	72186
Karnataka	110.87	132880	Assam	65.35	54618
Average	**120.79**	**128879**	Odisha	76.9	64869
			WB	89.62	79984
* At prices constant. at 2011-12			**Average**	**80.97**	**66903**

Unlike the James' study, significant income differential in the High-high and Low-low categories exist amongst Indian Telecom Circles falling in two categories.

4.4 Impact of GDP on Diffusion

A cursory look at tele-density of various Indian states and their per capita GDP reveals that GDP and tele-density are positively correlated. A plot of per capita GDP at current prices in March 2017 of various telecom circles and tele-density there in March-2019 is given in figure 8(a). It may be noted that the lag in timing of GDP has been taken purposely as a lag is expected in the cause impacting the dependent variable. The two-year lag is somewhat arbitrary- however, it was preferred since the correlation in case of two-year lag was stronger. A simple linear regression of underlying data reveals that relation of tele-density (D) with the per capita GDP (P) can be depicted as under:

D= 71.814 P + 30.605; P with a lag of two years being expressed in terms of 100 K Indian Rupees.

The associated standard error, t-stat & P-value are given in Table 4. Accordingly, the Null hypothesis H_0: The wireless tele-density in India (D(t)) is not significantly correlated with the per capita GDP can be clearly rejected even at 99.9% Confidence level and it can be concluded that a large part of prevalent wireless tele densities in a circle can be explained

Table 4. Descriptive parameters on Tele-density & GDP Correlation

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	30.60477	8.82629	3.467456	0.002945
GDP	71.81381	7.837361	9.16301	5.49E-08

based on prevailing GDP. However, Scatter diagram of tele-density and GDP growth rate for various Indian States do not show any correlation, as shown in fig 8(b) & 8 (c) leading us to infer that tele-density has not been able to boost the GDP growth rate as no clear correlation appears to exist between GDP growth rate and tele-density of various circles as well. It may be noted that Delhi with a tele-density of 237.94% and 236.30% in March 2015 & March 2016 respectively with a GDP growth rate of 11.03% and 7.54% during FY 15-16 and 16-17 respectively has not been plotted in figure 8(b) merely to facilitate enlarged view of the scatter of other telecom circles. To further confirm that the impact of tele-density on GDP growth rate in India is not significant, a scattergram of all 19 circles for a six-year period 2012-18 was plotted as shown in fig 8 (d) which also does not exhibit any pattern. Further, to completely rule out the impact of tele-density on GDP growth rate- it is important to understand the behaviour of individual circles across the years- and to confirm that the depiction of individual growth pattern is not lost in aggregation. However, the circle wise plots for the same period shows negative correlation in 6 out of 19 circles. Further, average of coefficients of tele-density (independent variable) in the regressed linear expression is 0.1122% implying that an increase of 0.1122% in GDP growth rate is expected for every 1% increase in tele-density. It is also noted that despite very limited period data- the correlation is so weak that the regression equation in most of the circles does not pass the t-test even at 75% significance level. Accordingly, while more conclusive results on this may be obtained on extending the data set- it can safely be concluded that the tele-density and GDP growth rate correlation, if any is quite weak.

4.5 Impact of Technology on Diffusion

Almost since commencement of wireless services in India – the mobile telephony has been provided in India on two major technologies- GSM & CDMA.

The growth of subscribers on these two technologies is shown in Figure 9 below. It may be seen that the slope of CDMA curve is very often steeper- however, from March 10 onwards- it has been consistently declining and in Sept-18, the CDMA subscriber numbers are ~0. The rapid diffusion of mobiles till 2010 is partly because of both the technologies parallelly augmenting the overall adoption of mobile phones. At the same time, decline of CDMA numbers and its subsequent elimination is one of the reasons the diffusion speed has significantly dropped from 2010-11 onwards. While there are various reasons for the decline of CDMA technology all over the world- accounting for both the technologies existing simultaneously in our diffusion model could have made it more robust.

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However, reliable data for subscribers based on technology (and circle wise) is not available and hence the same has not been done in this study.

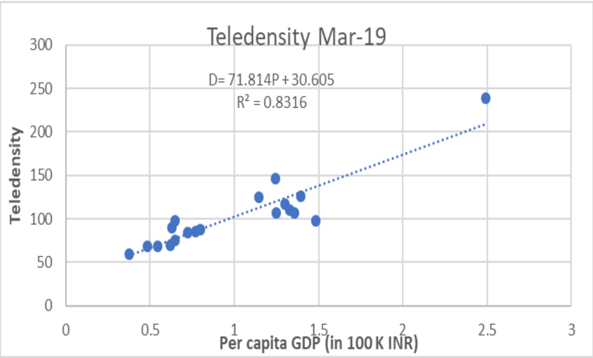

Fig. 8(a). GDP (in 100K INR) in 2017 and Tele-density correlation.

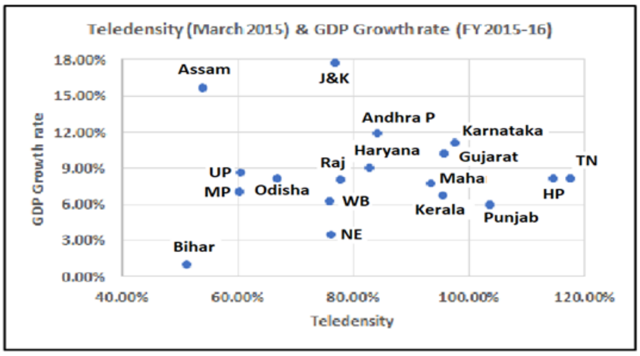

Fig. 8(b). Tele-density and GDP Growth rate scatter (2015-16).

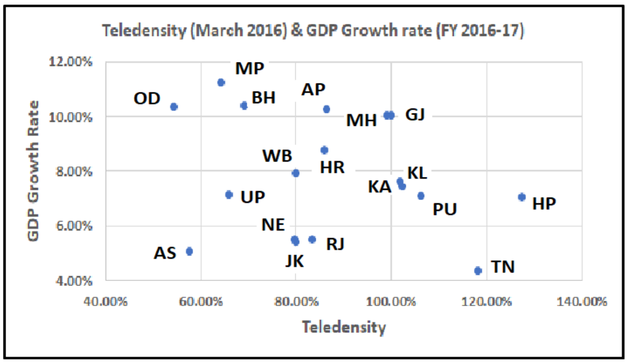

Fig 8(c). Tele-density and GDP Growth rate scatter (2016-17). Abbreviations used- AP= Andhra Pradesh & Telangana, AS=Assam, BH= Bihar & Jharkhand, GJ= Gujarat and Daman & Diu, HP= Himachal Pradesh, HR=Haryana, MP= Madhya Pradesh & Chhattisgarh, OD=Odisha, JK= Jammu & Kashmir, KL= Kerala, KA= Karnataka, MH=Maharashtra & Goa, NE= North eastern states except Assam, PU= Punjab & Chandigarh, RJ= Rajasthan, TN= Tamil Nadu & Pondicherry, UP= Uttar Pradesh +Uttarakhand, WB= West Bengal, Sikkim and A & N islands.

4.6 Impact of Fixed Line Telephony and Other Substitutes on Diffusion

Fixed phone penetration was quite insignificant at the time of commencement of mobile telephony in India. Further, in view of larger infrastructure requirement- it appears that the new operators did not have much interest in rolling out fixed line infrastructure where the incumbent public sector units- BSNL & MTNL remain a dominant player with almost two third of overall phones. These two factors have led to a situation

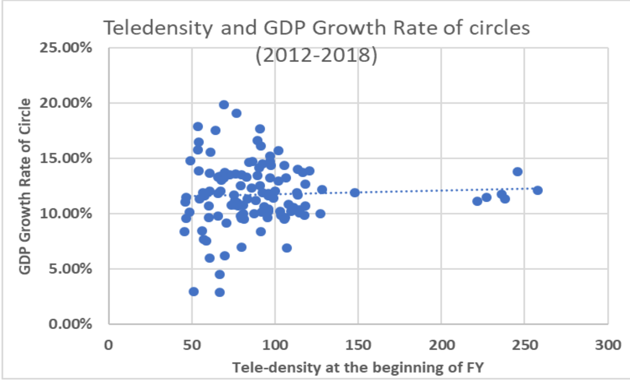

Fig. 8 (d). Tele-density & GDP growth rate scattergram for the period 2012-18.

where fixed lines have neither acted as substitutes nor accelerator due to networking effect. The mobile telephony has, however, acted as substitute of fixed line telephony eating away its share as fixed lines have been consistently declining. Fixed line connections have come down from approximately 41.42 million telephone connections in March 2005 to 21.7 million in March 2019. Fig. 19 and Table 5 clearly show the same.

V. SCOPE OF FURTHER RESEARCH

The current study has limited itself to macro level diffusion pattern at the country level and does not deal with operator specific or circle specific diffusion of mobile telephony. Accordingly, while the diffusion models used in this paper exhibit the chronological growth in subscriber numbers and tele-density, they do not detail the strategies adopted by operators to stimulate the diffusion to create a distinct competitive advantage for themselves. Further, while impact of GDP, digital divide and regulatory developments have been separately touched upon, they have not been integrated in the model. Efforts may be made to develop an integrated model after correlating and analysing the historic developments with the business strategy being followed by various telecom operators as well as the policy of the government and their outcomes in different time periods with due regard to the evolution of demand & pricing in view of evolving competition, evolving regulation and evolving technology. Further, this research does not consider complementarities or substitution effects of internet telephony, video calls from computer, google applications and WhatsApp on mobile voice demand. Additionally, in view of multiple technologies and multiple generations of same technology being simultaneously deployed in the network by various operators– the impact of their interplay on consumer behaviour, service demand and on pricing (through bundled service offerings) will also form an interesting study. Finally, the impact of convergence of all services- cable tv, gaming, fixed line telephony, broadband internet services and mobile telephony on various operators is going to shape their survival- a detailed study of the variables involved along with their strategic significance will be quite interesting and rewarding.

Table 5. Growth rates of fixed and mobile telephone subscriptions

Financial Year	Growth of Fixed Line Subscribers (G_F)	Growth of Mobile Subscribers (G_M)
2009-10	-2.63%	49%
2010-11	-6.03%	39%
2011-12	-7.37%	13%
2012-13	-6.09%	-6%
2013-14	-5.69%	4%
2014-15	-6.67%	7%
2015-16	-5.15%	7%
2016-17	-3.25%	4%
2017-18	-6.52%	11%
2018-19	-4.87%	-2%

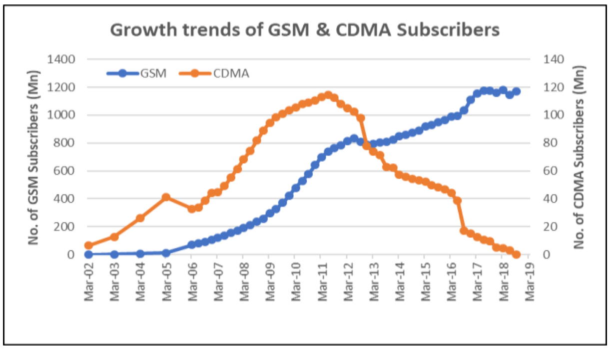

Fig. 9. Growth trend of GSM & CDMA Subscribers

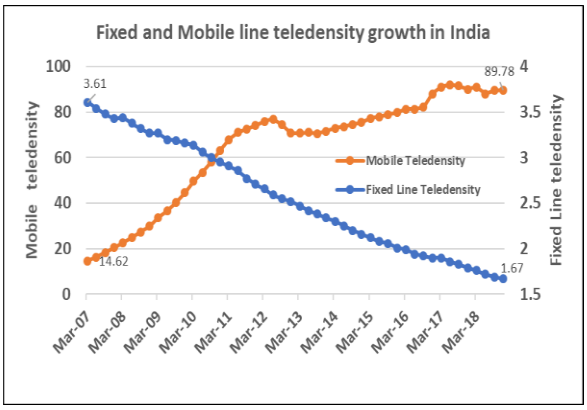

Fig. 10. Declining fixed line tele-density with increasing mobile tele-density

Actual field surveys can determine the impact on the reported diffusion pattern of multiple SIMs being used by one customer or SIMS being utilized by equipment and vehicle tracking systems etc. This will lead to more accuracy on the inferences made for the adoption speed and pattern. Finally, the growth studies should also have a perspective of impact of competitive intensity and price elasticity of demand, which is not covered in this paper and shall be presented separately.

VI. CONCLUSION

The study of existing Literature establishes that in Indian context, while income is a significant determinant of mobile telecom penetration, its correlation with GDP growth rate is scanty. Additionally, mobile phones are clear substitutes of Fixed lines in India and do not enjoy strong network effects possibly because of very low fixed line tele-density. The three diffusion models do not significantly differ on their prediction about saturation tele-density which is determined to be in the range of 85.48 to 88.17 against actual tele-density of 88.90 at the end of September 2019. All the diffusion curves show reaching the top end of the S curve and subsequently the CAGR of mobile subscriptions is barely exceeding the population growth rate. Clearly, unless there are significant changes in causal variables viz: GDP, electricity availability and allied infrastructure, data needs of people due to changes in occupational pattern etc. – the growth shall remain sluggish in near future. In the short run, marginal decrease in subscriber numbers and consequent increase in VLR percentage cannot be ruled out due to the impact of consolidation in the operator space and removal of inactive numbers from subscription list. This may bring the tele-density closer to that predicted by the diffusion models discussed in this paper. It is also noted that with majority of population still being rural, policy interventions from government, particularly in altering the causal variables for bridging the digital divide has significant potential to alter the diffusion pattern.

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