Technology Interactions in the Presence of Network Effects: Fixed Telephony, Mobile Telephony and the Internet

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Abstract

Forecasts of the diffusion paths are critically important when evaluating the launch of a new product. In the world of communications, predicting the adoption of products becomes an even more challenging and uncertain task as a consequence of the network externality effects. In this article we posit a diffusion model that, first, accounts for this effect by considering endogenous growth in the market potential: the bigger the size of the network of users, the higher the value of the products for other consumers, and second, accounts for the interaction effects between three technologies: fixed telephony, mobile telephony and Internet. We examine the level of fit of three functional forms for market potential: constant, exponential and linear, controlling for price and income effects. Using a dataset of 195 countries we find that firstly, mobile telephony and Internet are fully complementary; secondly, fixed telephony fosters the diffusion of mobile telephony, which on its turn cannibalises the diffusion of fixed phones; thirdly, fixed telephony facilitates the diffusion of Internet, but Internet diffusion does not have any significant effect on fixed telephony diffusion. These results can help build more robust scenarios to foresee the impact of the VOIP on the telecommunications industry.

INTRODUCTION

The diffusion of mobile telephony and Internet connectivity led to high growth and rapid technological change in the telecommunications industry, affecting both country total factor productivity and the bottom line of service providers (Basu, Fernald, Oulton and Srinvasan, 2003; Brynjolfsson and Hitt, 1995, 1996; Dunne, Foster, Haltiwanger and Troske, 1999). Despite of their tremendous impact on productivity levels, telecoms were apparently unable to appropriate most of the value created. Their poor financial performance has been used to blame sector managers for lack of professional and methodologically sound forecasting practises (Minoli, 2003). Given the size of the industry and its impact on productivity, telecom operators and governments share interest in forecasting the penetration of new technologies, especially disruptive ones.

Voice-Over-Internet-Protocol (VOIP) is believed to be a disruptive technology, which is expected to drive the price of voice transfer to zero, leading to a de facto convergence between telephony and the Internet. However, there are no studies that evaluate the pattern of diffusion of telephony and the Internet technologies, taking into account the substitutability and/or complementarity between them and the involved network externalities. We present the first study of this kind and shed light on what can be expected about the Internet and telephony convergence in the future.

Many models in marketing and economics explain diffusion of new products (see Mahajan, Muller and Bass (1990) for a comprehensive revision of the literature). The interest in understanding the factors that drive diffusion processes has been partly motivated by the need to produce adoption forecasts. All existing models of telecommunications diffusion implicitly treat telephony and Internet as completely independent, so that the effect of their complementarity or substitutability on the diffusion path has never been studied. In this paper, following the methodology proposed by Elberse, Ladron de Guevara, and Putsis, (2002) we estimate between and across countries network externalities for fixed telephony, mobile telephony and the Internet. Next, we model technology diffusion and include a network externality effect where the consumer's utility is a function of the network size (Katz and Shapiro, 1986; 1992; 1994; for mobile telecommunications: Gruber and Verboven, 2001a; 2001b). We use three alternative functional forms, constant, exponential and linear, for the "ceiling variable", which determines the total market potential. We find that mobile telephony and Internet are fully complementary; fixed telephony foster the diffusion of mobile telephony, which on its turn cannibalises the diffusion of fixed phones and that fixed telephony facilitates the diffusion of Internet, but Internet diffusion does not have any significant effect on fixed telephony diffusion. These results are robust for all three functional forms for market potential and all models show high levels of overall fit (between 0.7421 and 0.9199). The two control variables included in the estimations, price and income, show also similar effects in all models and for all technologies.

The paper is organized as follows. Section 2 provides a brief description of the most relevant technological aspects of fixed and mobile telephony and the Internet. Section 3 describes the diffusion process with network externalities and product interactions. Section 4 describes the data and presents the empirical results. Section 5 concludes, discusses the limitations and suggests implications for public policy and business strategy.

TECHNOLOGY

Fixed-line telephony can be considered a saturated segment in the telecommunications sector. In many countries it is a natural monopoly traditionally operated by state-run telephone companies or recently privatized heavily regulated monopolies plagued with bureaucratic ineffectiveness. Fixed network has stopped growing and is actually declining in many countries if *Integrated Services Digital Network* (ISDN) lines are not taken into account. ISDN lines add between two and thirty "virtual" connections to an existing fixed line (ITU, 1999). The reason for the increase in ISDN is the growing demand for Internet access that is still dependant on the fixed-line network (ITU, 1999: p. 2-3). Internet dial-up traffic generates one-third of local telephone traffic in many European countries and in most of the world it far exceeds international telephone calling (Minoli, 2003). In Australia, for example, 60% of the telecom service users say they need fixed-line phones for their Internet Access (data from a AMR Interactive survey of 1915 Australians, quoted in *Telecom Asia*, June 2005, p. 12). Most of Internet users in the world rely on fixed-line phone connection and as of 2000 only 7% had more bandwidth through *Integrated Services Digital Network* (ISDN) and less than 3% had broadband local access such as *Asynchronous Digital Subscriber* Line (ADSL).

Voice Over Internet Protocol technology transmits signals over a broadband Internet connection. As someone is talking, voice is assembled in packets of information by a Digital

Signal Processing device in a computer, cell phone or regular phone; then the information is broken up into smaller packets, transmitted over broadband Internet and translated with Digital Signal Processing back into voice at the receiver's computer or phone. VOIP converges voice, video and data into one network offering huge savings and arena for new services. In Japan, for example, VOIP reduced communication costs in half for companies like Tokyo Gas, Hitachi and Mitsubishi Corp.(Majumdar, 2005). Development of VOIP depends, however, in large extent on the development of the fixed-line network where private investors are reluctant to inject money because of the inherent monopolistic nature of the industry. On the contrary, private investments in cellular telephony network has been frequent, as the segment has been associated with high profitability, limited price competition, limited financial risk and short pay-back period for the initial investment (Gruber, 1999).

The development of cellular services was triggered by the spectrum constraints that characterized the use of radio spectrum of earlier radiotelephone systems. First Generation mobile phones had the characteristic to find access to different available frequencies, which made it possible to ensure a connection as long as the signal was available. Following in the early 90's, came Second Generation phones with GSM (Global System for Mobile Communications) which revolutionized the whole industry by providing several important features: connectivity, compatibility between areas, SMS (Short Message System), the SIM (Subscriber Identity Module) card which allows for a single chip to contain all of the users information and use it on different phones, and later on Internet access, Java downloads and even music. Third Generation (3G) mobile phones are still under development, but the goal is to have wireless data high-speed transfers, multimedia services and better reception. In addition 3G will be the first global standard for mobile networks as until now there has been about a dozen different standards around the world (Minoli, 2003).

All three technologies, fixed-line telephony, cellular telephony and the Internet are characterized by network externalities and some degree of complementarities or substitution (see Table 1). In essence, any projection for the future of the telecommunications sector is partial if it ignores the interaction among these technologies and the network externalities they enjoy. Below we offer the first study in the field that takes into account both factors simultaneously.

TABLE 1 ABOUT HERE

THE MODEL

We present a model, which accounts for both the network externality effect (by considering endogenous growth in the market potential) and the interaction effects between fixed telephony, mobile telephony and Internet.

Modeling the network externality effects

For many technological innovations, the value of a product for a given consumer depends upon the total number of existing users. This network externality effect is particularly relevant in the case of communication technologies where externalities are assumed to be present in the diffusion process. The model presented here accounts for this effect by considering endogenous growth in the market potential: the bigger the size of the network of users, the higher the value of the product for other consumers, hence the more likely are the potential consumers to adopt the technology.

Consistent with Rogers (1995) and Dekimpe et al. (1998), for a country *i* we define the social system, S_i, as the population within which the technology diffuses. Along the diffusion process, only a fraction, C_i, of the social system has sufficient intrinsic utility to adopt the technology. The diffusion process then takes place within a subset of the social system, which constitutes the market potential, $M_i = C_i S_i$. When network externalities are present, the utility that consumers derive from adopting a technology is a function of the network size. As a consequence, market potential varies significantly according to the stage of the diffusion process. In line with this approach we extend the Dekimpe et al. (1998) diffusion model by endogenizing the market potential along the diffusion process. We consider that for every period *t*, the proportion of the population with a positive 'network utility', C_i, is a function of the level of adoption, N_i/S_i, where the variable N_i denotes the cumulative number of adopters in country *i*.

We propose three alternative functional forms the "ceiling variable" that determines the total market potential size. The functional forms are presented in Table 2. Figure 1 illustrates the implied growth patterns for the "ceiling variable" C_i as a function of the level of adoption.

TABLE 2 ABOUT HERE

FIGURE 1 ABOUT HERE

In Model 1 we assume no network effects, resembling the Dekimpe, Parker and Sarvary (1998) framework with an exogenous constant ceiling. Under this assumption, the technology diffuses along a fixed proportion of the social system. The adoption process reproduces the standard Bass-model dynamics, approaching the adoption level of (1-θ) in the long run.

In Model 2 we assume that the ceiling variable follows an exponential cumulative distribution. The parameters θ and ϕ reflect the shape and growth of the market potential as a function of the network size. The expression $(1- \theta)$ denotes the fraction of the social system willing to adopt the innovation at the early stage. The value for the network externality parameter ϕ relates to the slope of the market potential function and indicates the magnitude of the externality. For higher values of ϕ, the network effects are relevant and the market potential grows fast, approaching a higher fraction of the social system S_i even when diffusion is relatively modest. However, the lower ϕ, the larger the network size required to reach a significant fraction of the social system willing to adopt the technology.

In Model 3 the market potential grows linearly with the adoption level. As in Model 2, the parameters $(1- \theta)$ and ϕ reflect the fraction of early adopters and the magnitude of the externality, respectively. Importantly, for $\phi = 0$, models 2 and 3 resemble the Model 1, where the market potential is a constant fraction $(1- \theta)$ of the social system.

Diffusion process with network externalities and technology interactions

1. In this section we propose a model that accounts for a diffusion process within an endogenous market potential, a market potential, which grows continuously as the social network expands. Extending on the standard assumptions of Mahajan and Peterson (1985), when network externalities are present the number of new adopters of a

technology (1=Internet; 2=mobile telephony; 3=fixed telephony) for a given country i is expressed by the following equation:

$$n_{xi}(t) = \left[\alpha_x + \left(\beta_x + \gamma_x PCGDP_{\$95_i}(t)\right)\frac{N_{xi}(t-1)}{C_{xi}(t-1)S_{xi}(t-1)} + \sum_{y \neq x}\delta_{xy}\frac{N_{yi}(t-1)}{S_{yi}(t-1)}\right](C_i(t-1)S_i(t-1) - N_i(t-1))\, Z_{xi}(t), \quad x = 1,2,3 \tag{4}$$

where *n(t)* is the number of new agents adopting the technology *x* (*x* =1,2,3; 1=Internet; 2=mobile telephony; 3=fixed telephony) in time period *t*, and $N_{xi}(t-1)$ is the number of cumulative adoptions at the end of the previous period. For every technology *x*, the expression $C_{xi}(t-1)S_{xi}(t-1)$ denotes the market potential, where the endogenous ceiling is determined by equations (2) and (3). The parameter α_x is the coefficient of external influence. We allow the coefficient of internal influence to be a fuction of the per capita Gross Domestic Product, $PCGDP_{\$95}$, expressed in 1995 dollars. The parameter β_x is the coefficient of internal influence. The complementarity-substitutability effects of related technologies y≠x on technology *x* are captured by the set of parameters δ_{xy}. The ratio $N_{yi}(t-1) / S_{yi}(t-1)$ denotes the adoption level of the interacting tecnology. Finally, $Z_{xi}(t)$ denotes the set of marketing-mix variables that affect the diffusions process of technology *x* in country *i*.

Modelling the market potential as a process that depends on the size of the network affects the diffusion process in some important aspects. The market potential becomes an endogenous variable determined simultaneously by the law of motion for the endogenous ceiling (2)-(3) and the dynamic equation (4). The assumptions on the distribution function for the proportion of the social system C_i that become potential adopters depending on the size of the network, drives the speed and shape of the diffusion process (see Table 2). Low proportion of early adopters $(1-\theta)$ and high externality parameter ϕ characterize a diffusion process presenting strong network effects. As a result such diffusion process will have a small number of adopters during initial periods because a very small proportion of the social system is willing to adopt the technology when the network size is small. The market potential is therefore minimal early in the diffusion process, but increases continuously as new adoptions occur. The larger the network effect, the later the diffusion peak occurs. This 'lagged' diffusion pattern characterizes many technological innovation processes (see Elberse, Ladrón-de-Guevara and Putsis, 2002 for a detailed analysis of the diffusion dynamics when network effects are present).

EMPIRICAL ANALYSIS

Data, estimation and results

In order to evaluate the interactions between fixed telephony, mobile telephony and the Internet we use the International Telecommunications Union data set from 1991 till 2003 for 195 countries. The data consists of 1438 country-year observations.

Equation 4 is estimated for fixed telephony, mobile telephony and Internet. The $Z(t)$ term includes the cost of a 3 minute off-peak local call from a fixed-line phone when the diffusion of fixed telephony is considered and the cost of a 3 minute off-peak local call from a mobile phone when mobile telephony diffusion is estimated. We do not include price variables for the estimation of Internet diffusion due to lack of reliable internationally comparable data. In the estimation of the diffusion of mobile and fixed telephony we follow previously proposed methodology (Bass, 1969) and use not only the current price of a call but also the change relative to the last year's price level. The inclusion of this variable reduces the number of observations to 567 for mobile telephony and 607 for fixed telephony. When estimating the diffusion of Internet technology we control for income effects ($PCGDP_{\$95}$) and do not include marketing mix variables. As a result, the total number of observations is 1110.

All models have been expressed using time-discrete formulations. This may introduce a time interval bias. However, previous research has suggested that coefficients do not differ significantly according to the estimation method (Mahajan et al. 1986). The models are estimated using the whole time series in order to examine the level of fit to historical data. Table 3 contains the level of fit for the nine models. All of them show high levels of fit ranging from 0.7421 to 0.9199.

TABLE 3 ABOUT HERE

The equations of the model are non-linear, so we use Maximum Likelihood as an estimation procedure. Given that we estimate three simultaneous equations for the three technologies that interact we use the Full Information Maximum Likelihood method. In Table 4 we show the sign of the interaction terms (δ_{xy}) for the three technologies and their statistical significance. Table 4 reveals how the technology listed in the column affect the technology on the row.

TABLE 4 ABOUT HERE

We find that mobile telephony and the Internet are fully complementary: mobile telephony diffusion fosters Internet diffusion and Internet diffusion fosters mobile telephony. This full complementarity reflects a generalised demand for better and timelier information as mobile phones have been traditionally used for voice transfer while Internet is more data-centred. This specialisation of the type of information to the specific communication technology, however, is challenged by the technological convergence materialised in products like mobile Internet and VOIP. In fact, full complementarity implies that these hybrid technologies will strictly dominate the traditional concepts of mobile telephony and Internet connectivity.

Our second result is that mobile and fixed telephony cannibalise each other: fixed telephony fosters the diffusion of mobile telephony, which on its turn cannibalises the diffusion of fixed phones. Where fixed phones exist they are perceived as a complement to mobile phones. However, in countries where fixed line network is underdeveloped and mobile phones come, the demand for fixed lines is reduced. This result supports the idea that mobile technologies are an excellent substitute for traditional technologies in those developing countries where governments cannot guarantee sufficiently the assets of the investors. In spite of the underdeveloped institutions for private investors' protection mobile telephony will develop in such conditions because, among other factors described in Section 2, it is a less risky substitute for fixed-line telephony (Andonova, 2006). Our finding that diffusion of mobile phones is negatively affected by per capita income confirms this interpretation. Poor countries with less developed fixed-line network substitute fixed for mobile phones. Unsurprisingly we also find that lower prices help the diffusion of mobile phones.

Finally, we find that fixed telephony facilitates the diffusion of Internet, but Internet diffusion does not have any significant effect on fixed telephony. These type of interaction, where the old technology (fixed line) facilitates the use of the new technology (Internet) but the rising popularity of the new technology does not necessarily affect the use of the old one, is called auxiliary (Bayus, 2000). Fixed telephony is a very mature market with no prospects for growth. In our data between 1991 and 2002 the average number of telephone lines per household is 0.77. The lack of significant income and price effect on the diffusion of fixed telephony confirms our interpretation of the interaction between fixed telephony and the Internet. Fixed telephony is so mature that none of the factors we analysed can put it on a growth path. In essence, we find that fixed telephony helped Internet growth and indirectly the creation of a major rival, VOIP, while the Internet does not have an effect on the very mature fixed line market. The economic implications of these results, the limitations of our analysis and venues for future research will be discussed in the last section.

IMPLICATIONS AND CONCLUSIONS

Forecasts about the future of the telecommunications industry will invariably fail if we do not take into account two important factors: network effects and interaction effects between different communication technologies (complementarity-substitutability effects). There are numerous studies on this industry, which consider the network externality effect but, to the best of our knowledge, there is no study, which simultaneously takes into account network and interaction effects. The importance of interaction effects has been recently rediscovered and research on “other products, complements or substitutes” for the diffusion of goods has been invited (Shocker, Bayus and Kim, 2004). Here we perform the first large-scale study using data on the telecommunications industry paying attention to the interactions between fixed telephony, mobile telephony and the Internet for 195 countries between 1991 and 2003. Our models show high level of fit and the interaction effects among the three telecommunication technologies are very robust across models.

According to our results fixed line telephony works as an enabling technology for the diffusion of the Internet. The Internet diffusion however, shows no effects on the diffusion of fixed telephony. With the advance of VOIP we expect that the diffusion of Internet actually decrease the number of fixed lines in use, a process that has already started in many countries with high Internet penetration levels. VOIP, as an alternative to the fixed telephony will harm the traditional business of many state-owned monopoly providers of fixed telephony. These will be forced to change their strategies and possibly become providers for Internet connectivity, which fosters Internet diffusion even further. The new business focus, however, will strip them from most of the power because the market structure of Internet connectivity is more competitive than the natural monopoly situation telecoms enjoyed as fixed telephony providers. In fact, by changing the competitive dynamics for fixed telephony VOIP makes consumers less dependent on regulators to guarantee their interest against the telecom monopoly.

The interdependence between fixed telephony and the Internet can also explain to a large degree the existence of digital divide between developed and developing countries. Developing countries, often unable to guarantee the assets of private investors, lack the funds to finance a widespread telephone network, which is the enabling mechanism that guarantees Internet diffusion. So, the digital divide is divide in basic telephone infrastructure that fosters Internet diffusion and this divide had been in place long before the Internet was invented.

Our results also highlight the interaction between fixed and mobile telephony. Fixed telephony fosters the diffusion of mobile telephony and the two technologies evolve as complementary. Mobile phones are used predominantly for voice communication and fixed lines are used for Internet access and data transfer. This complementarity is not symmetric, however, as mobile telephony is found to be a substitute for fixed lines. In developed countries where competition drives priced down faster, fixed telephony is substituted by mobile. In developing countries with long waiting lists for a fixed line and in remote and rural areas, mobile telephony is substituted by mobile. The underdeveloped fixed line network in developing countries limits the complementarity effect between fixed and mobile telephony and introduces mobile technology as a direct substitute for fixed lines. Taking into account the duality in the interactions between fixed and mobile telephony reveals that the same technologies might be complements or substitutes in different countries depending on the development of local telecommunications.

Lastly, our study shows that mobile phones and the Internet are full complements. This implies that companies in either field should search for strategic alliances in the other filed because the convergence of mobile and the Internet will be the winning service in the future. Taken from this perspective the prices paid for 3G licences might not be so exaggerated. Even thought 3G networks are still under development they seem to offer the integrated product that consumers long for.

In this study we show that the interactions across related telecommunications technologies actually affects the diffusion of each technology in a nontrivial way. This result should be taken seriously by managers engaged in forecasting the future of the telecommunications industry as it might considerably improve their ability to foresee risks and opportunities. We have sketched some of these risks and opportunities here but we are sure that many more are left unaddressed.

Table 1: Complementarity and substitutability

	Fixed-line telephony	**Mobile telephony**	**Internet**
Fixed-line telephony		COMPLEMENTARITY *In developed countries mobile phones are predominantly used for voice communication, while fixed lines are maintained for Internet connectivity and data transfer.	COMPLEMENTARITY *Fixed lines enable most Internet connectivity in the world.
Mobile telephony	SUBSTITUTABILITY *In underdeveloped countries with long waiting lists for a fixed line and in remote and rural areas, mobile telephony is an alternative to fixed telephony. *In developed countries where competition in cellular drives prices down faster, fixed telephony is substituted by mobile.		COMPLEMENTARITY *3G mobile phones are enabled to perform an intensive data transfer and Internet content providers are ready to broaden their supply as soon as 3G networks become fully operational.
Internet	SUBSTITUTABILITY *Local cable TV network is an alternative to fixed-line telecoms for Internet connectivity. VIOP technology used over cable TV network is substitute for fixed-line telephony.	SUBSTITUTABILITY *Internet connected mobile devices using VOIP are substitutes to mobile phones.	

Table 2: Functional forms for market potential

	Functional Form	Equation	
Model 1	Constant	$C_i = (1- \theta)$	(1)
Model 2	Exponencial	$C_i = 1\text{-}\theta\ e^{-\phi*(Ni/Si)}$	(2)
Model 3	Linear	$C_i = 1\text{-}\theta + \phi*(N_i/S_i)$	(3)

Table 3: Level of fit

	Internet	Mobile	Fixed
Model 1	0.8997	0.7421	0.7525
Model 2	0.9199	0.7650	0.7523
Model 3	0.9160	0.7528	0.7522

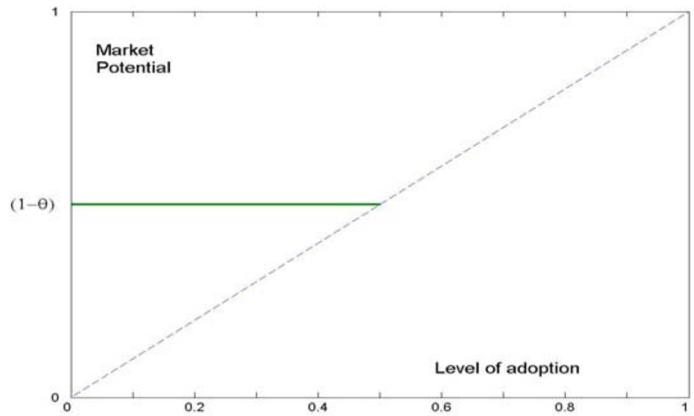
Table 4: Complementarity-Substitutability effects between information technologies (δ_{xy})

		Internet	Mobile	Fixed
Model 1	Internet		+ S	NS
Model 1	Mobile	+ S		- S
Model 1	Fixed	+ S	+ S	
Model 2	Internet		+ S	NS
Model 2	Mobile	+ S		- S
Model 2	Fixed	+ S	+ S	
Model 3	Internet		+ S	NS
Model 3	Mobile	+ S		- S
Model 3	Fixed	NS (+)	+ S	

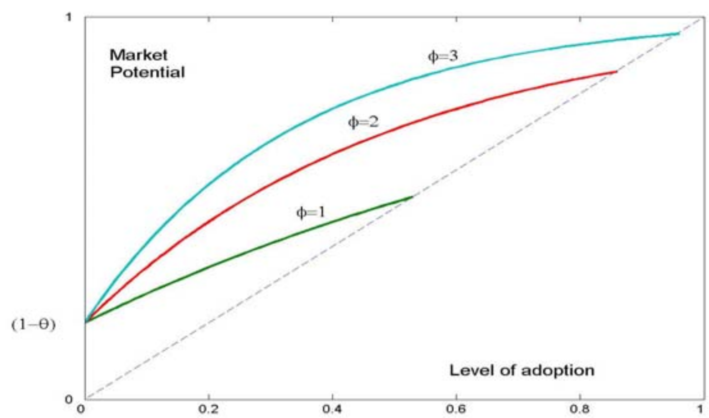
NS= Not statistically significant at 5%
+S= Significant at 1% , positive coefficient
-S= Significant at 1% , negative coefficient

Figure 1: Market Potential, $C_i(t)$, as a function of the level of adoption $\left(\frac{N_i(t)}{S_i(t)}\right)$

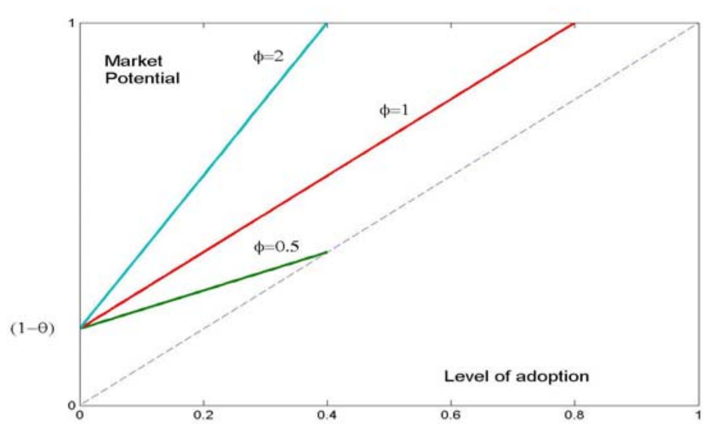
Model 1 (Constant)



Model 2 (Exponential)



Model 3 (Linear)



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