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## Abstract

*IS scholars have been studying the diffusion of Information and Communication Technologies (ICT) for some time now and certain research methods have emerged as the dominant ones in this body of literature. In this paper, we first note these methods citing representative studies and then present an alternate approach to studying ICT diffusion using systems dynamics (SD). Any diffusion, by nature, is a temporal phenomenon. The essence of SD is to uncover the underlying network of cause-effect relationships that is generating a temporally evolving behaviour. Thus it is a natural for studying ICT diffusion, particularly when diffusion is driven by complex interactions among contextual variables. SD has not received much attention in the ICT diffusion literature, but this method has strengths that complement those of the other methods currently in common use, thereby enhancing our understanding of the phenomenon. The characteristics of SD also make it particularly appropriate for studying ICT diffusion in the Pacific Asia region which is characterized by substantial differences in contextual variables that drive ICT diffusion, such as literacy rates, economic development and infrastructure sophistication, besides having wide diversity in cultural norms.*

*Keywords: Information Technology, Telecommunications, Diffusion, System Dynamics.*

# 1 INTRODUCTION

Information and Communications Technologies (ICT) have had a profound impact on the activities of individuals, organizations and nations. It is not surprising therefore, that nations have made it a priority to facilitate the diffusion of ICT. It may be tempting to think that as the price/performance profile of ICT continues to improve, ICT will, inevitably, become pervasive. Unfortunately, the ‘digital divide’ stubbornly persists even today (Billon et al 2009) despite numerous policy interventions over the years to alleviate it. The diffusion of ICT is a temporally evolving phenomenon resulting from a complex interaction between technology characteristics and those of the environment in which it is embedded. The latter includes quantifiable characteristics such as GDP per capita and literacy rates, as well as those that are harder to quantify, such as tolerance for piracy and importance of privacy protection. Given the importance of the phenomenon, ICT diffusion has attracted the attention of scholars for quite some time. Different methods have been used in the literature, each bringing its own strength to bear to help us understand one or more aspects. Unfortunately, it is precisely the interaction among these different aspects – i.e. technology, economics and human behaviour – that has not been studied as intensively, even though it is crucial to the phenomenon. In this paper, we first briefly summarize the dominant methods that have been used to study ICT diffusion. We then use the summary as a backdrop to introduce an alternate method to study the phenomenon, that of system dynamics (SD) (Richardson 1996), which focuses specifically on capturing interactions among the multiple aspects. The central tenet of SD is ‘structure causes behavior’, where structure refers to the network of cause-effect relationships among the contextual variables that drive ICT diffusion. SD has not received much attention in the ICT diffusion literature, but has strengths that complement those of other methods in use, and has the potential to not only enhance our understanding of the phenomenon, but also assist in making policy interventions to accelerate diffusion.

# 2 LITERATURE REVIEW

There is a vast literature on ICT diffusion but we make no attempt to summarize its findings here. Rather, since the focus of this paper is on making the case for an alternate *method* to study ICT diffusion, the aim of this section is to discuss a select few articles that are representative of the *methods* that have been used in the literature to study the phenomenon (Dwivedi et al 2010). This will help us understand the strengths and weaknesses of current methods and help contrast them with those of the SD method. We do not claim that SD is superior to the others – it will be evident that no one method can claim superiority. However, we do assert that SD’s strengths complement those of the others and helps us get a more complete understanding of ICT diffusion.

Case studies have been widely used and have offered important insights into ICT diffusion. Such studies are generally characterized by very rich contextual detail at a fine level of granularity. They are largely qualitative in nature although simple descriptive statistics may be included from time to time (Atsu et al 2010, Udo et al 2008). As a recent example of this method, Lahtinen (2012) studied patterns of ICT usage by young Finnish boys in the home context and concluded that their personal characteristics are a better indicator of adoption than their social and environmental factors. A recent study in Jamaica (Brown and Thompson 2011) offers another example. Here, the authors investigated various eGovernment initiatives undertaken by the government to aid ICT diffusion specifically looking at the Jamaican customs department. They found that innovative directive, standards and subsidies were important contextual factors that facilitated diffusion. A study of ICT diffusion in the Canadian K-12 school system (Dibbon 2003) is yet another example of this method. It found that engaging students in the co-creation of curricular content was a powerful force in speeding up the diffusion of ICT in school education settings. Using focus groups, Aleke et al (2011) investigated the adoption of ICT by small scale agribusiness in southeast Nigeria. They found that visible social imperatives and social factors such as language and cultural norms play as important a role in diffusion as the technical characteristics. While case studies enable us to explore the diffusion phenomenon in all its complexity, we are necessarily limited to the organization under study, which means that generalizability of findings is difficult. Nevertheless, case studies offer an ideal platform for exploratory investigations to help identify important contextual variables and understand the actual process of diffusion.

While exploratory studies help identify relevant contextual variables and processes, more broad based empirical studies have also been carried out in the literature to quantify the ICT diffusion pattern itself using one or more metrics of the phenomenon. One class of studies takes indicators of ICT diffusion over time and fits the data to some well known diffusion functions using statistical estimation techniques. As an example, Dergiades and Dasilas (2010) fitted data on the number of mobile subscribers in Greece from 1993 to 2005 to the well known Gompertz and Logistic curves using nonlinear least squares method. Based on this quantification, they were able to conclude that the introduction of prepaid phones in 1997 and a third mobile operator in 1998 boosted the diffusion process. They also concluded that the growth in mobile subscribers had started to slow down by 2005. Note however, that there is no attempt to quantify the relationship between diffusion and any of its determinants. Similar studies have been carried out for Colombia (Gamboa and Otero 2009) and Taiwan (Chu et al 2009). A recent study (Kim 2011) analyzed data on Internet use between 1994 and 2007 and found that a logistic S-curve fits the data very well. Associated panel data analysis also led the author to conclude that exposure to the technology at school and in the workplace was an important driver of initial use and email usage was the single most important predictor of continued Internet use. There are many other studies in the same vein that attempt to quantify ICT diffusion by fitting data on one or more indicators of diffusion to well known growth curves. Such quantification can also form the basis for predictions of ICT diffusion levels.

A different class of empirical study attempts to quantify the relationship between ICT diffusion and one or more determinants using techniques such as cluster analysis, factor and discriminant analysis, structural modelling and path analysis. Typically, the determinants have been identified through qualitative explorations of the kind mentioned at the beginning of this section. Using Internet hosts, Internet users, mobile phones and personal computers as indicators of ICT, Baliamoune-Lutz (2003) studied the relationship between ICT and several determinants. The author found that diffusion was influenced by income and trade policies but, contrary to expectations, not with education level. Shirazi et al (2010) examined whether foreign direct investment and trade openness explain disparity in ICT diffusion between the Asia-Pacific region and the Islamic middle eastern countries. They found that trade openness has a beneficial effect on ICT diffusion on both regions, but the impact of foreign direct investment was mixed. While it had a positive impact in the Asia-Pacific region, it had a negative impact in the middle eastern countries. Using a PROBIT model, Nair et al (2012) found that access, education, type of rural community and age were key determinants for mobile phone use rural areas in Malaysia. Using discriminant analysis, Lal (2009) analyzed the adoption of ICT by small and medium scale businesses in Jamaica and Mauritius. He found that the cost of communications was a major impediment to adoption across firms, but firm size and employee education level were important determinants of the extent of adoption by firms. Richardson (2011) has a study teacher adoption of IC skills in Cambodia.

The unit of analysis in the preceding studies was mostly at the firm (Haller and Siedschlag 2011) or country level. Another subset of studies in the literature examines adoption/diffusion of ICT at the individual level. The leading example of this type of study is the Technology Acceptance Model (Davis 1989) and its numerous variants. In this study, using a structural model consisting of latent variables, perceived usefulness and perceived ease of use were found to be important determinants of user acceptance of information technology. This initial set of determinants have been augmented and/or validated for many different settings (e.g. Leng et al 2011, Celik and Yilmaz 2011).

Collectively, the qualitative and quantitative methods represented by the studies cited above, have progressively improved our understanding of ICT diffusion in different ways. Case studies have served to bring out the complexity of the phenomenon and, from time to time, have identified aspects of the phenomenon that had been previously overlooked. Since technology keeps changing, case studies and other qualitative analyses, such as structured interviews, continue to inform us about the changing nature of the phenomenon. The quantitative analyses have been useful for forecasting purposes and for understanding which determinants may have a stronger impact on the phenomenon than others. These findings are also informative for making policy interventions. Organizations and nations want to derive value from ICT and often engage in purposeful interventions to facilitate the diffusion of ICT. It would be useful to complement the methods noted above with one that assists policy makers in deducing the likely consequences of their planned interventions. For instance, government might consider allocating a specific part of the radio spectrum on a discounted basis to facilitate broadband penetration in rural areas. Can the impact on ICT diffusion be assessed in terms of how much and how fast? The current methods, while helping us to understand the phenomenon and its determinants, do not directly assist in quantifying the consequences of planned interventions. This, in part, motivates us to make a case for the system dynamics (SD) approach in the next section. Other benefits of the SD approach will also be noted along the way

# 3 SYSTEM DYNAMICS

System dynamics (SD) (Coyle 1998; Richardson 1996) offers an alternate approach to study ICT diffusion and has complementary strengths. We provide a brief overview here, since the methodology has not been commonly used in the Information Systems literature. Further technical details may be found in the references just cited. SD is a mathematical language to represent the causal structure of a system, and its basic tenet is ‘structure causes behaviour’. The domains from which systems are drawn can be extremely varied. Among others, they may be physical (e.g., rainfall patterns), economic (e.g., price controls), or managerial (e.g., strategy formulation). The distinctiveness of SD is that it links causal structure to system behaviour in computational form. To contrast SD with the methods summarized in earlier sections, consider an iceberg metaphor shown in Figure 1. The portion above the waterline represents the events and patterns that characterize the phenomenon of concern. In the case of ICT diffusion, this may consist of events such as the introduction of an ultra cheap tablet PC, the introduction of a 3G network, or the pattern of penetration of mobile telephones in a developing country (Gamboa and Otero 2009). The portion below the waterline in Figure 1 refers to the contextual variables that have a material impact on the diffusion related events and patterns above the waterline. Examples of such variables have been shown in the diagram. The methods surveyed earlier can be mapped on to this iceberg metaphor to identify their strengths and weaknesses. For instance, we noted earlier how case studies have helped to identify important variables underlying ICT diffusion. These would be variables below the waterline in Figure 1. Different statistical methods have helped quantify diffusion patterns and predict about how it will evolve in the future. They have also helped to quantify the strength of the association between diffusion patterns and different determinants – i.e. variables below the waterline. However, all these methods share one characteristic in common. They view the underlying mechanism that is generating ICT diffusion, as a black box. Note that identifying underlying variables and showing that they are correlated with diffusion is quite different from identifying the underlying mechanism. SD opens that blackbox and seeks to explicitly uncover the causal relationships among the underlying variables and the diffusion behaviour that they generate. In doing so, it offers a different view of the diffusion phenomenon, one that is no seeking to only describe the observed phenomenon, but which also offers the opportunity of altering variables to affect the observed behaviour in desirable ways. After all, if we do not understand the mechanism by which a variable affects the observed diffusion pattern, it would be difficult to determine the magnitude and direction of planned interventions that would affect the diffusion pattern in desirable ways. A small analogy may reinforce this point. Let’s say I am flying a plane and I know that the plane’s movements are changed in certain directions by the rudder (yaw), ailerons (roll) and elevators (pitch). But let’s assume I do not know the physics of flight. In other words, I do not know the cause-effect relationships among these three determinants and the collective impact of their interaction on the flight pattern. In such a scenario, if I want to turn left, I will be inclined to just initiate a roll. But this will reduce lift and if I do not also bring the nose up a bit using the elevators, not only will I turn left but I will also head towards the ground! This simple example shows that while knowing the determinants is a necessary step in understanding a dynamic phenomenon, understanding the cause-effect relationships among the determinants and other contextual variables is crucial if one is planning to make interventions to affect the phenomenon in some desired way.

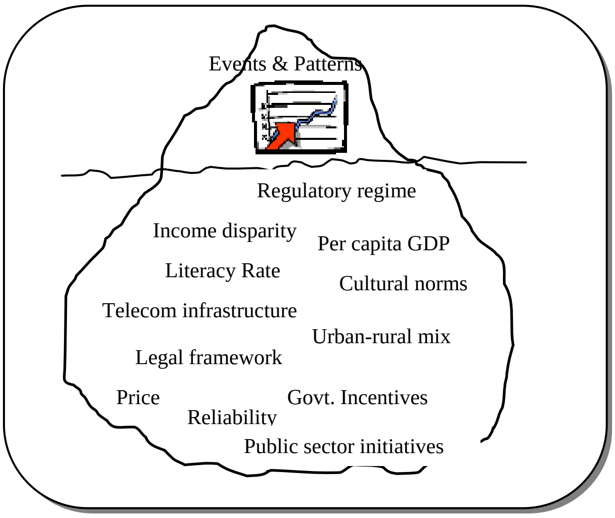


*Figure 1. An Iceberg Metaphor for 'Structure causes behavior'.*

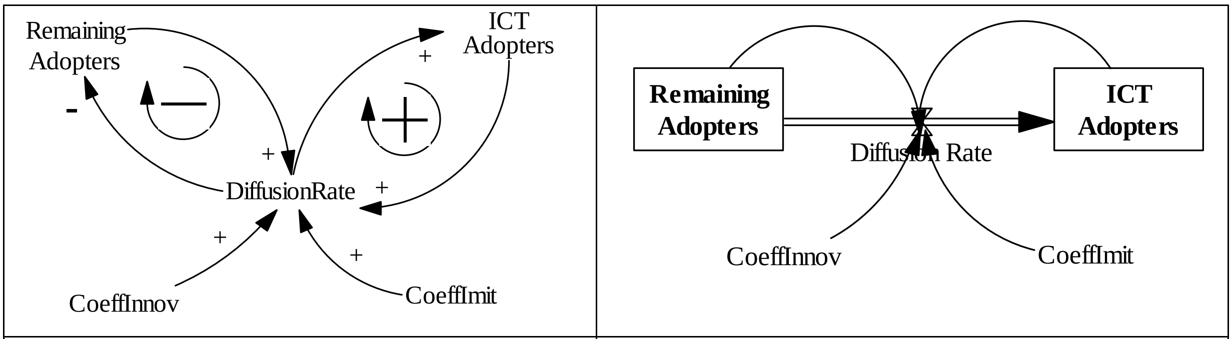
We illustrate the basic difference between SD and the previously documented methods with a simple ICT diffusion example. Consider the well known Bass diffusion model (Bass 1969) that has been the starting point for numerous diffusion studies, including ICT diffusion. The first assumption in this model is that there are a small number of individuals, called innovators, who will acquire a new product/service because they are inclined, behaviourally, to try new things. Then as the new product starts penetrating the market, current owners will, through a word of mouth process, induce new individuals to purchase the product. This is called imitation and those buyers are called imitators. The Bass diffusion equation can be stated as:

$\frac{f(t)}{1-F(t)} = p + qF(t)$ where the potential market size has been normalized to 1 and:

f(t) is the rate of change of the installed base at time t– i.e. the diffusion rate
F(t) is the total number of adoptees at time t
p is the coefficient of innovation
q is the coefficient of imitation

This process leads to the well known S-shaped diffusion curve that is so well established in the marketing literature and spawned the terms innovator, early adopter, early majority, late majority, and laggard (Rogers 1983). The Bass equation can be rewritten as: $f(t) = p[1 - F(t)] + qF(t)[1 - F(t)]$. In other words, the rate of diffusion $f(t)$, at time $t$, consists of the number of innovators at time $t$ and the number of imitators at time $t$. The former is the number of potential adoptees left at time $t$, $[1 - F(t)]$, multiplied by the coefficient of innovation $p$. The latter is the result of word of mouth interaction between the number of people who have adopted $F(t)$, the number of remaining potential adoptees $[1 - F(t)]$ and the coefficient of imitation $q$. The causal structure underlying the Bass diffusion model, as implied by the equation above, can be expressed in SD in three different but equivalent forms as shown in Figure 2.

The first, called a causal loop diagram (CLD), appears in Figure 2(a). Links show cause-effect relationships and their polarities the direction of effect. A positive polarity means that the direction of change in the effect is the same as the direction of change in the cause. It does not mean that the effect only increases in magnitude. If the cause decreases (increases) in magnitude, the effect decreases (increases) in magnitude relative to what it would have been without the decrease (increase) in cause. A negative polarity means the direction of change in the effect is the opposite of the direction of change in the cause. It does not mean that the effect only decreases in magnitude. Feedback loops are closed sequences of causal links. A positive feedback or reinforcing loop has an even number of negative links, and generates exponentially increasing or decreasing behaviour. A negative feedback or balancing loop generates compensating behaviour in that the loop always acts in a way to bring the system back to a designated target state. Figure 2(a) shows two feedback loops, one positive the other negative. This causal structure can now be used to deduce the temporal behaviour of ICT diffusion. The positive loop captures word of mouth effects. The more *ICTadopters* we have, the stronger the word of mouth effect, and the higher the *DiffusionRate*, leading to even more *ICTadopters*. This reinforcing loop generates the exponential growth. However, Figure 2(a) also shows a negative feedback loop. The higher the *DiffusionRate*, the lower the pool of *RemainingAdopters* (represented by the negative link), which in turn lowers the *DiffusionRate*. In other words, the rapid initial growth in *DiffusionRate* ultimately runs into the limited number of *RemainingAdopters* and chokes off further growth in *ICTAdopters*. The CLD of Figure 2(a) can be translated to the second representation, called a stock-flow model, as shown in Figure 2(b).



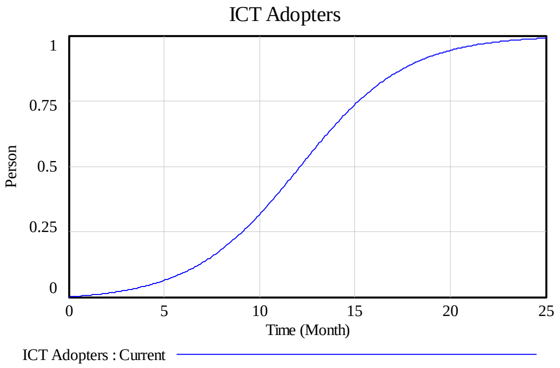
*(a) Causal Loop Diagram* *(b) Stock Flow Representation*

Diffusion Rate(t+Δt)=
(CoeffInnov*RemainingAdopters(t)) +
(ICTAdopters(t)*CoeffImit*
RemainingAdopters(t))

RemainingAdopters(t+Δt) =
RemainingAdopters(t)
– DiffusionRate(t)*Δt

ICT Adopters (t+Δt) = ICT Adopters (t)
+ DiffusionRate(t)*Δt

CoeffInnov = 0.005, CoeffImit = 0.35
Initialvalue RemainingAdopters=1



*(c) Equation Representation* *(d) Diffusion Behavior of Structure*

*Figure 2. SD Representation of Bass Diffusion Model*

Figure 2(b) has exactly the same variables as 2(a), but shows new symbols—a box and pipes with regulators on them. The former represents stock variables—i.e., accumulations of things. The latter represent flows—i.e., rates of change of things. These rates are controlled by information flows, represented by the thin directed arrows in the figure. For instance, the coefficient of innovation, *CoeffInnov*, and the coefficient of imitation, *CoeffImit*, are information items that drives the variable *DiffusionRate*. The stock flow diagram (SFD) of Figure 2(b) is a visual form of the collection of equations shown in Figure 2(c). This is a discrete-time version of the differential equations describing how *ICTAdopters* changes over time. Therefore, the collection of equations in Figure 2(c) can be simulated to generate the behaviour of *ICTAdopters* over time, and this is shown in Figure 2(d). The behaviour is the well known S-shaped diffusion curve. As this exercise shows, the SD method allows us to represent the causal structure underlying a temporally evolving phenomenon such as ICT diffusion. There can be little argument that CLDs and SFDs are more comprehensible representations of causal structure compared to a collection of differential equations. However, if closed form solutions can be obtained to the diffusion equation, as can be done for the Bass model and simple extensions of it, then SD has little to add. However, when the diffusion phenomenon under study is driven by multiple interacting variables, equations characterizing the phenomenon usually do not lend themselves to closed form solutions. This is where SD's ability to deduce behaviour by simulating the underlying causal structure can help us to understand the phenomenon in a way that purely analytical methods cannot. In the next subsection, we first note some of the distinctive characteristics of the Asia Pacific region that have an impact on ICT diffusion, and then proceed to show how SD can be used to combine these characteristics into more holistic models of diffusion. These models can be used to not only explain observed diffusion patterns, but also deduce the potential consequences of policy interventions. After all, ICT diffusion is not a phenomenon of nature that can only be observed and understood. Rather it is an artifact of human activity and its behaviour is therefore subject to being shaped by purposeful policy interventions.

### 3.1 Asia Pacific Country Characteristics

The Asia Pacific region is characterized by wide variations in geography, literacy rates, infrastructure sophistication, economic development and political evolution. There is also variation in cultural norms, administrative structures, extent of private sector participation and the role played by non-governmental organizations. These characteristics have significant impact on the diffusion of ICT. Compare, for instance, Singapore and Indonesia (CIA 2012). The former is a compact urban country of about 700 Sq. Km. while the latter is about 1.9 Million Sq. Km. in area consisting of 17,500 islands of which about 6000 are inhabited. The physical challenges of deploying communications infrastructure in the two countries would be very different, as would the costs and delays involved in doing so. For instance, wireless technologies, particularly fixed and mobile satellite services, may be more attractive to build out communications infrastructure in a widely dispersed archipelago like Indonesia. A few more contrasts which are relevant for ICT diffusion, are noted in Table 1.

On the regulatory front, Singapore had merged their National Computer Board with the Telecommunication Authority of Singapore in 1999, into the Infocomm Development Authority (IDA), motived by the growing convergence between information technology and telecommunications. We see intent here to take a more integrated view of ICT in regulatory matters. One of IDAs key responsibilities is to create an innovative and competitive infocomm environment that is both pro-consumer and pro-business. Indonesia, on the other hand, has a more traditional regulatory structure which focuses purely on the telecommunication side of ICT. Moreover, it is relatively young. The Indonesian Telecomm Regulatory Agency, BRTI, was approved in 2003 and mandated with improving competition in the telecomm sector. But it has been under-resourced and has experienced growing pains (Lee and Findlay 2005). These differences in country characteristics will have significant impact on the diffusion of ICT. For instance, the significant rural concentration in Indonesia, coupled with the much lower per capita GDP, implies a much lower ability to pay for ICT products and services compared to Singapore. This will surely constrain the demand for ICT diffusion in Indonesia relative to Singapore. However, as connectivity improves, the value of ICT will become evident to an increasing segment of the population and will, in turn, strengthen the diffusion of ICT. Notice also, that a strong segment of the economy in Indonesia is agriculture based, while a large portion of the Singaporean economy is in services. It is well known that the services sector is a big consumer of ICT. Hence the mix of activities in an economy will also be a driver of ICT diffusion. The differences between the two countries in terms of religious, linguistic and ethnic composition also plays a role in ICT diffusion. ICT content has tended to be predominantly English and western in tone. Availability of locally relevant content, in local languages, would be an important determinant of diffusion in countries such as Indonesia, where the population is not universally fluent in English.

| | Indonesia | Singapore |
|---|---|---|
| Population | 248 million | 5.35 million |
| Urban Population | 44% | 100% |
| Median Age | 28.2 years | 40.1 years |
| Predominant Religion | Muslim 86% | Buddhist 42.5% |
| Population growth | 1.04% | 1.99% |
| Literacy | 90% | 92.5% |
| Per capita GDP (ppp) | \$4,700 | \$59,900 |
| GDP distribution (agri, industry, services) | 14.9%,46%, 39.1% | 0, 28.3%, 71.7% |
| Income inequality (Gini coeff) | 36.8 | 47.8 |
| Mobile phones | 220 million | 7.3 million |
| Internet hosts | 1.34 million | 992,786 |
| Internet Users | 20 million | 3.2 million |

*Table 1. Comparison of Country Characteristics - Singapore and Indonesia*

The two countries selected above are simply illustrative of the significant diversity in the Asia Pacific region in terms of the factors that are relevant to ICT diffusion. Moreover, given that many Asia Pacific countries are late entrants in the ICT sector, there is a conscious effort on the part of these countries to engineer more rapid and effective diffusion of ICT through purposeful policy actions. Hence it is helpful to employ methods for studying ICT diffusion that are oriented not just towards describing and characterizing the phenomenon, but can also help deduce the likely consequences of planned policy actions – i.e. quantifying the potential impact of these actions on the phenomenon. In the remainder of this section, we will demonstrate how SD can help meet this need.

## 3.2 SD Models of ICT Diffusion

The SD representation of the basic Bass diffusion model presented above makes simplifying assumptions that are not consistent with the diversity of countries characteristics that was just discussed. Nevertheless, it is interesting to note that many of the ICT diffusion studies summarized earlier in the paper make very similar simplifying assumptions. We now proceed to show, with progressively more comprehensive models, how SD can be used to include contextual variables, leading to richer models of ICT diffusion that are more representative of the context within which diffusion actually occurs in the Asia pacific region.

### *3.2.1 Separating Out Telecom Infrastructure*

In many countries, including most countries in the Asia-Pacific region, telecommunications is subject to regulatory constraints and oversight while computing is much less so. The situation with Singapore’s IDA, which oversees both computing and telecommunications, is in fact quite atypical. The evolution of these two components of ICT tends to be driven by different forces, even though they are joined at the hip due to the fact that the lines between computing and networking are getting increasingly blurred. So we proceed to show how the basic SD diffusion model from Figure 2 can be refined to separate out the telecomm infrastructure growth process. Figure 3 shows such a model. To conserve space, we only show a stock-flow representation instead of all three representations that were shown for the basic model. The new variables introduced in this disaggregated model are shown in italics. Telecomm infrastructure, represented by the stock variable *TelecomCap*, is built out at a certain rate, *Buildrate*, that is determined by relevant governmental policies. For instance, if the telecomm sector is still state owned with very limited competition, *Buildrate* will be likely be lower than if the sector has been reformed by introducing a healthy dose of competition and private sector investment. The telecomm capacity, *TelecomCap*, will in turn determine the overall network performance experienced by ICT users, represented by the variable *NetworkPerf*. The Bass model in Figure 2 had assumed that the coefficient of imitation, *CoeffImit*, remains constant over the duration of the adoption lifecycle. In the case of ICT diffusion however, the reality is that this imitation coefficient will clearly depend on the network performance, *NetworkPerf*, experienced by ICT users given how ubiquitously computers connect to networks these days. If *TelecomCap* does not keep up with the pace of new ICT adopters, this will degrade *NetworkPerf* appreciably, which in turn will restrain the effective impact of imitation. In other words, the effective coefficient of imitation, *EffctvImit*, is a function of the nominal coefficient of imitation *CoeffImit* and the impact of network performance on imitation, *PerfImit*. This dynamic relationship between network capacity and adoption rate has been captured in Figure 3 by the following feedback loop *ICTAdopters* → *CapUtil* → *NetworkPerf* → *PerfImit* → *EffctvImit* → *DiffusionRate* → *ICTAdopters*. By separating out the expansion of network capacity, the SD model in Figure 3 also allows us to also examine the impact of certain dimensions of diversity in user populations. For instance, ICT adopters in the service sector tend to be quite sensitive to network performance. If *NetworkPerf* degrades, there will be negative word of mouth effects in this user segment, slowing down the adoption process. On the other hand, rural users tend to be much more tolerant of *NetworkPerf* degradation as even a slow connection offers them so much value compared to pre-adoption conditions. This diversity can be represented by two different functional forms for *NetworkPerf*, and the impact on adoption can be determined.

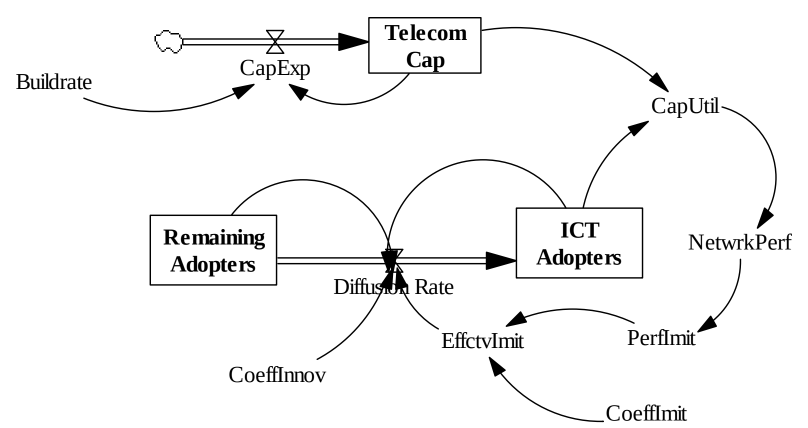


*Figure 3. ICT Diffusion With Telecom Infrastructure Separated*

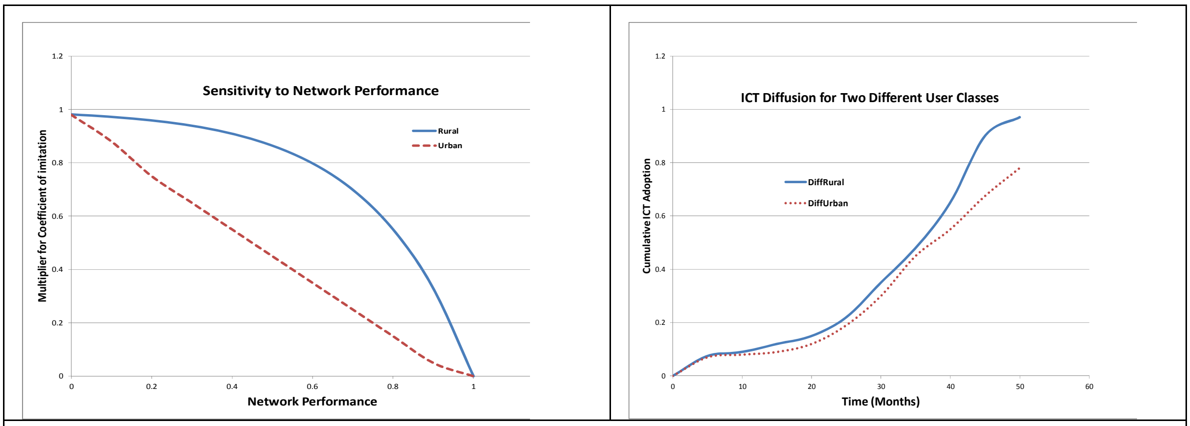


*Figure 4. ICT Diffusion for Two Different User Classes*

Figure 4 shows the results of simulating the model for the two different classes of potential adopters. The segment that is more sensitive to network degradation experiences a slower growth pattern and the model shows the magnitude of the difference as well. This quantification can help in setting policy parameters that determine how rapidly the network needs to be built out in a way that addresses the diversity in adopter segments.

Consider another aspect of ICT diffusion that is particularly relevant in many developing countries. Here, from time to time, technology is introduced to potential adopters through planned governmental (Alghamdi et al 2011) or private sector initiatives because the adopters, due to their social and economic circumstances, are unlikely to self-start the adoption process. Examples include the eChoupal project in India (Ali and Kumar 2011), where farmers were empowered, through ICT, to improve all aspects of farming from production to sales, and e-Gvernment initiatives in Malaysia (Zakaria et al 2011) intended to make certain government services more accessible to common people. From a modelling perspective, these contexts are characterized by extremely low coefficients of innovation, *CoeffInnov*, and the initiatives are intended to boost this coefficient for a certain limited period of time to get the diffusion process started. The hope is that, once started, the diffusion process will sustain itself through the imitation mechanism. These kinds of initiatives can be modelled as a ramp function for *CoeffInnov* as shown in the left half of Figure 5. The height of the ramp depends on the magnitude of resources devoted to the initiative while the length of the ramp is the duration of the initiative. The right half of Figure 5 compares the diffusion patterns of two scenarios, with and without such an initiative. Once again, notice how it is now possible to quantify the improvement in timing and magnitude of benefits resulting from such an initiative.

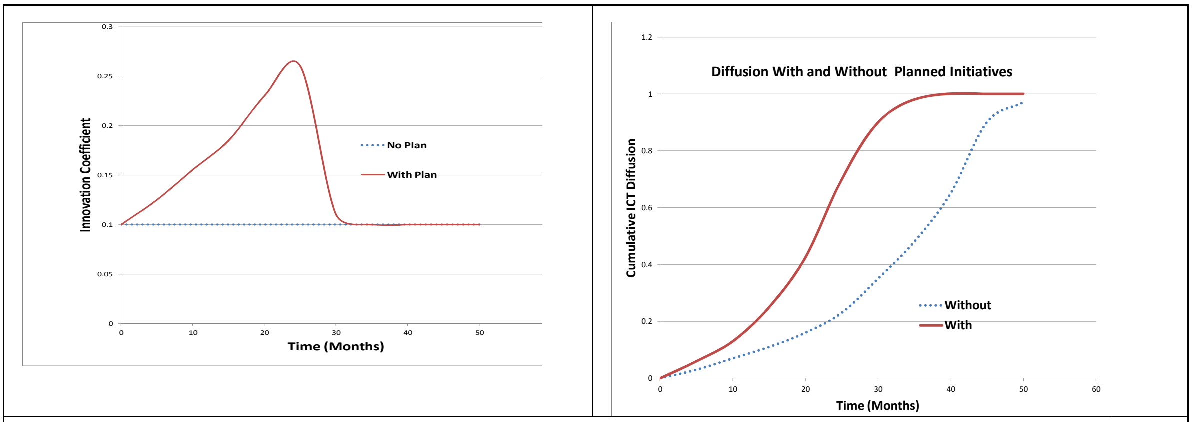


*Figure 5. Impact of a Planned Diffusion Initiative*

### *3.2.2 Modeling Delays in ICT Diffusion*

As ICT diffusion takes hold, its benefits take hold and, over time, the potential pool of adopters also increases. This is a long term impact, but a very significant one in terms of it's effect on economic and social development (Vu 2011). SD is particularly useful for studying these long term impacts as it is able to explicitly model delayed cause-effect relationships. Figure 6 shows a SD model that builds on the one in Figure 4 to include this longer term developmental impact. Notice the feedback effect from *ICTAdopters* to *PerceivedValue* to *NewPotentialAdopters*. The double hash mark on the link from *ICTAdopters* to *PerceivedValue* represents the delay associated with ICT adoption taking hold and for individuals to recognize that value. Like other diffusion phenomena, delays are an integral part of ICT diffusion and the SD methodology is explicitly able to represent different types of delays functions and compute their impact on different policy actions. As an illustration, we have carried out a sensitivity analysis in which the model in Figure 6 was simulated for different values of *BuildRate*, the network build out rate. Results are shown in Figure 7. Higher *BuildRate* requires higher levels of investment and the resulting diffusion patterns allow us to see how much faster adoption will occur and quantify the timing of benefits. In turn, this would allow for more informed cost benefit analyses of ICT investments.

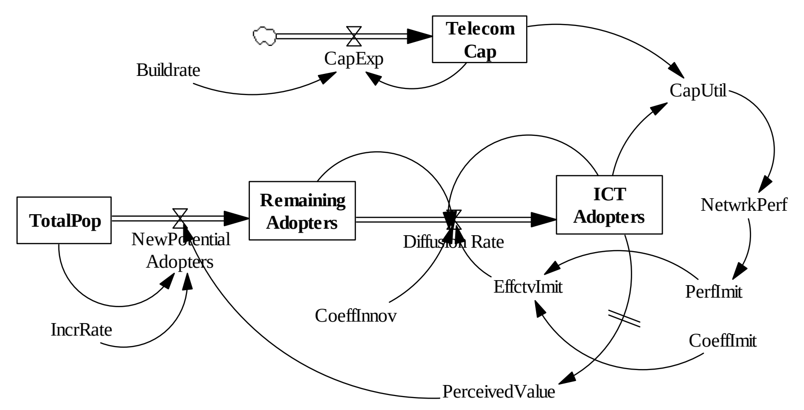


*Figure 6. Capturing Feedback effects of ICT Based Development*

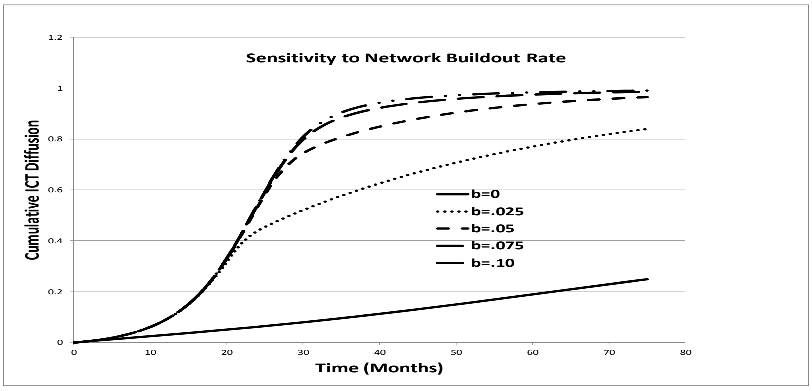


*Figure 7. Sensitivity of Diffusion to Different Network Buildout Rates*

### 3.3 Assessment of the SD Method

The preceding collection of models illustrates the applicability of the SD method in studying the dynamic phenomenon of ICT diffusion. SD forces us to explicitly represent the underlying mechanics of diffusion by identifying variables and the cause-effect relationships that exist among them. This is an important distinction from currently dominant methods for studying ICT diffusion, which usually focus on outcome variables and/or determinants, but view the diffusion mechanism itself as a black box. The strength of the SD approach is that it allows one to take a holistic look at the different contextual variables, their interrelationships, and the resulting impact of this interaction on ICT diffusion . Moreover, it does so using a computational representation that can be simulated. As such it helps us go beyond characterizing the phenomenon ex post, to actually examining the consequences of different policy actions that are intended to help shape the diffusion pattern in desirable ways. The SD method is capable of representing nonlinear relationships among variables underlying ICT diffusion and can explicitly capture delayed effects. Collectively, this makes the SD method particularly well suited for a decision support role when planning for policy interventions. The SD method has also been used to study the diffusion of other technology mediated phenomena, where there is an interaction between technology and non-technology factors. In (Dutta and Roy 2003) for example, the authors used the SD approach to examine the evolution of the security profile of an organization based on interaction between technology and behavioural factors. Dutta, Roy and Seetharaman (2008), examine the temporal patterns to usage of content in open fora, such as Wikipedia, using the SD method. They model the interaction between characteristics of the technology platform and behavioural attributes that drive usage behaviour and attempt to explain how some fora are self sustaining in terms of usage, while others fail to sustain themselves. However, this flexibility and power of SD does come at a cost. SD models can be much more demanding in terms of the data needed to validate the various relationships. Fortunately, since ICT diffusion has been studied for quite some time, many of these individual relationships have already been established empirically in the literature. SD allows us to integrate these relationships into a more holistic view of the phenomenon.

# 4 CONCLUSION

The diffusion of ICT is a complex phenomenon but one that has very significant consequences for individuals and organizations. The complexity arises from the multifaceted nature of interaction between the technology and the context in which it is embedded. No single methodology provides a full understanding of the phenomenon, but a select few methods have emerged as the dominant ones in the literature. The contribution of this paper lies in demonstrating the viability of another method for studying ICT diffusion, one that has complementary strengths to those in common use. Qualitative studies are very rich in contextual detail and help us understand the mechanics of the diffusion process. While they are weak in quantifying the diffusion process, these studies are very useful in identifying relevant variables and determinants, which then form the basis for quantitative modelling. The SD approach falls into the quantitative category, but it differs from other quantitative approaches to ICT diffusion in that it explicitly requires one to model the mechanics of diffusion. It is thus able to capture many contextual variables but at the same time this introduces more challenges for model validation. One example of integrating technology and non-technological characteristics into a technology diffusion model, albeit at a country not a regional level, can be found in (Dutta and Roy 2005), where the authors compare the diffusion patterns of Internet hosts in India and China. This work focuses more on the diffusion of telecommunications infrastructure but can be extended to include computing infrastructure and the interaction between telecommunications and computing. The Asia Pacific region is characterized by great diversity in cultural norms, geography, demographics, technology infrastructure, economic and political development. These contextual factors have a significant impact on ICT diffusion as shown in numerous case studies. The SD method is not a substitute for other methods, but it does complement them by offering a computationally powerful way to study the impact of these regional characteristics on the ICT diffusion phenomenon and assess policy interventions.

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