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A System Dynamics Model of Technology and Society:
In the Context of a Developing Nation

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ABSTRACT

Kenya has emerged in recent times as one of the fastest growing telecom markets in the world. There is not a single, widely used paradigm which has synthesised the various schools and theories dealing with technology and society. This article argues that the issue of mobile technology on society is a complex technical and social phenomenon that needs to be understood from both ICT and social science perspectives. This study used the concept of governance socio-techno-economic systems as the theoretical framework. System dynamics are used as both the methodology and tool to model the mobile industry impact on society. The study shows that the increase in social capital intensity is an important source of the economic growth. This increase will strengthen the accelerator mechanism of the economy and creates larger multiplier effects. The increase in social capital intensity can be obtained through managing innovation processes base on the development of education and the R&D capacity of the nation.

KEYWORDS

Causality, Information Society, Mobile Phones, Modelling, Policy, Social Construction Of Technology, System Dynamics

1. INTRODUCTION

Does technology shape society, or does society influence our technological choices? Is technological determinism a theory of society or a theory of technology? The debate on Science, Technology and Society (STS) studies has been animated by two opposite views on technology: one that affirms that technology shapes society, and the other that society shapes technology. The former, is commonly associated with the notion of technological determinism; while the latter could be labelled 'social shaping of technology' which covers various approaches, such as social constructivism and actor-network theory. Neither provides an overall view: but both have failed to give us a comprehensive view of technological change and the major forces driving social change.

This paper investigates the impact of technology usage on the society in Kenya. A recent paper by (Amos et al., 2018) looked at mobile industry governance in Kenya. It is an accepted view that technological progress is an extremely important, perhaps the most important, determinant in the growth in output per man. In the discussions of the role of technological change in the economy, the questions asked are how technological change affect different factors (capital and labor). As a milestone in the theory of economic growth literatures, Solow (1956) modelled the technological

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change through multiplying the production function by an exogenous increasing scale factor A(t). The term A(t) in the production function represents all the influences that go into determining output besides capital and labor. Changes in A overtime represent technical progress. The models that have been developed so far do not provide satisfying directions for policy purposes. For a developing country, the most important question is how to design a robust strategy of technological changes that can be expected to improve her national productivity considerably. It is important for policy design that the model has to have an appropriate policy space to explore the entry points for an evolutionary change. As a basis for design, the model structure and the behaviour of the model and its empirical relevance has to be fully understood. Not always do innovations involve the application of technology: organizational and service innovation. Technology by itself is of no significance unless it is translated into innovations. Innovation and diffusion are primarily economic and social processes which involve many other actors and behaviours besides those directly involved in the creation of technology itself (Dodgson & Bessant, 1996).

2. THEORETICAL FRAMEWORK

STS is a contested acronym: some understand it as 'science and technology studies', while others see it as 'science, technology and society' (studies) or 'social studies of science and technology'. For this paper STS stands for Science, Technology and Society, emphasizing the societal aspects of scientific and technological development. Concerns about S&T were born of World War II, when people recognized the complex and problematic, and sometimes undesirable, relationships between power and science. STS emerged clearly in the late 1960s as a social movement, besides other social upheavals that appeared then (e.g. environmental and feminist groups). Because of its origins, STS studies have often been critical of S&T developments and often try to propose ways to control S&T. Later on, in the 1980s, STS was reinvented and turned into an academic field, focused mainly on knowledge creation, rather than policy and control issues.

Some authors (Spiegel-Rosing, 1977; Teich, 2001) argue there is a divide between STS studies and policy-making. Others (Williams & Edge, 1996) affirm that some streams of STS studies (e.g. especially social shaping of technology) have been concerned with technology policy. It can be argued that these academic communities are quite differentiated, with very little overlap. This does not mean that STS scholars have not influenced policy-making, as it is not their main concern, while STP researchers do seek to affect policy directly.

STS started as a movement, with a critical view of scientific and technological development and its impact upon society, proposing alternatives to control S&T. STS later turned into an academic field, more interested in knowledge creation, having a strong disciplinary focus (sociological, philosophical, or historical). STP, according to some authors, grew out of the 'control' approach to STS.

The debate on STS has been animated by two opposite views on technology: one that affirms that technology shapes society, and the other that society shapes technology. The former, is commonly associated with the notion of technological determinism. There is no 'accepted' definition of technological determinism, and there are also various denominations (e.g. soft vs hard). Andrew Feenberg (2002) states that technological determinism is based on two theses:

- The pattern of technological progress is fixed, moving along one and the same track in all societies.
- Social organization must adapt to technical progress at each stage of development according to 'imperative' requirements of technology (Feenberg, 2002).

The main ideas behind social shaping are that technology:

- Is seen as a dimension of society rather than as an external force acting on it from a metaphysical beyond
- Does not follow its own momentum but is instead shaped by social factors, and,
- Is open to negotiation and change, while it is designed.

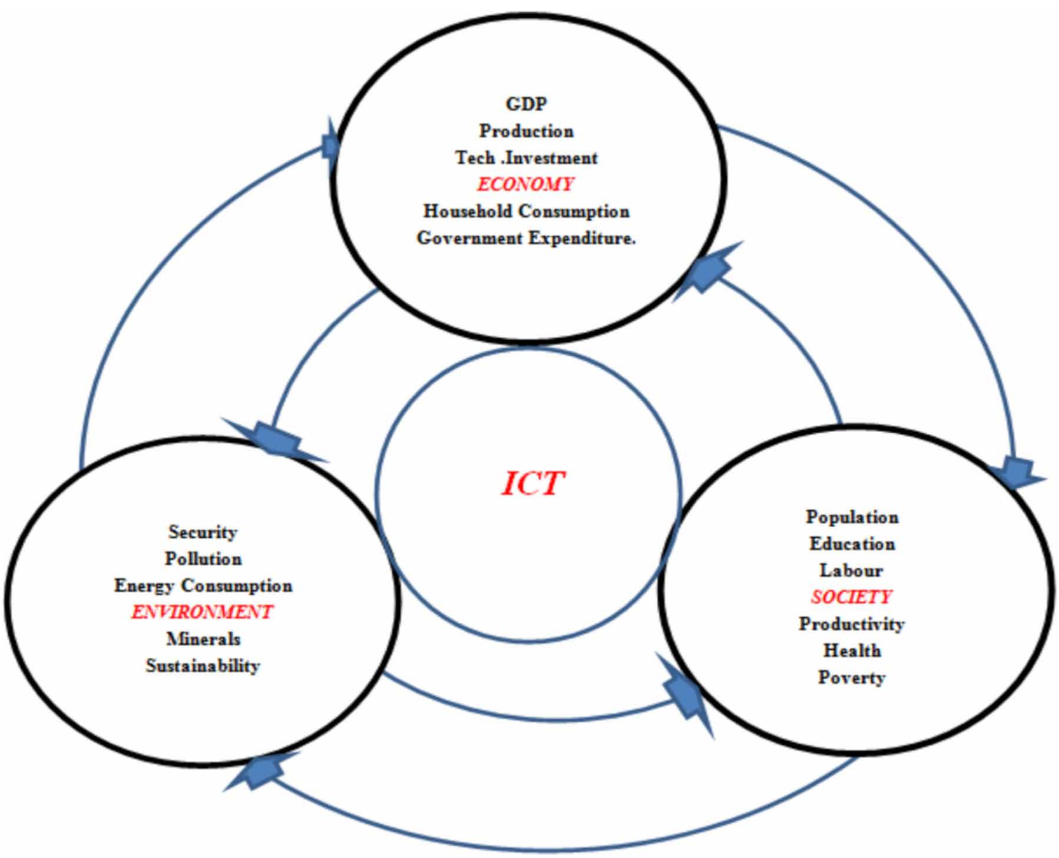
2.1 Integrated Societal, ICT and Economic Theories

For a general view, a high-level conceptual framework of the national model is illustrated in the figure 1 with the linkages among the economy, society, and environment sub-systems. Within each sub-system are the number of sectors, modules, and structural relations that interact with each other and with factors in the other parts.

The economy sub-system contains major production sectors (agriculture, oil, industry and services) as the supply side, which is characterized by Cobb-Douglas production functions with inputs of resources, labour, capital, and technology. Demand side (consumption, investment and government) is based on population and per capita income. The government sector generates taxes based on economic activity and allocates expenditures by major category, which then impacts the delivery of public services, subject to budget balances.

The Social sub-system contains detailed population dynamics; health and education challenges; and poverty levels. These recent sectors' effect in its turn determines population growth. Population determines the labour force, which shapes employment. Education and health levels, together with

Figure 1. A high-level conceptual framework of the interaction ICT, economy, society and the environment (PRISM and Knight, 2000, cited in PCE, 2002)



other factors, influence labour productivity. Employment and labour productivity affect the levels of production from a given capital stock.

The Environment sub-system tracks pollution from production and its impact on health. It also determines the consumption of natural resources and can determine the impact of the depletion of these resources on production or other factors.

The ICT issues at the centre of the diagram are so heavily interconnected with economy, society and environment that impact on most factors.

Based on this conceptual framework the national model will be constructed in system dynamic approach and modelling. In general, System Dynamics attempts to model the basic structure of a system to be able to capture the behavior that the system produces (Sterman, 2000). It is thus possible to give clear, quantitative cause-and-effect relationships. These relationships are constructed by identifying feedback loops that exist between objects within the system. These can be positive, negative, or stock-and-flow relationships. In feedback loops, a change in one variable affects other variables in the system over time (often including delays), which in turn affect the original variable. Identifying all these relationships correctly and explicitly is the means to understanding complex systems.

System dynamic modelling contains 4 phases in general: qualitative modelling, quantitative modelling, model testing and experimentation. During the stage of qualitative modelling, a causal loop diagram is drawn (Sterman, 2000). In the quantitative modelling stage, a stock flow diagram and a System Dynamic simulation model are created (Sterman, 2000). Following setting up the model, it is tested with available data. If it passes the testing, the model is used in experiments to generate information for system analysis.

Before discussing the applied stages in the present study, it should be taken into consideration that (Sterman,2000) stated that modelling is iterative. Iteration can occur from any step to any other step. In any modelling project, one will iterate through these steps many times (Sterman, 2000).

2.1.1 The Social Technical System (STS) Component

Socio-technical system refers to the inter relatedness of social and technical aspects of a system. In fact, itis much more complex than mixture of people and technology. Many of the individual actors in STS are difficult to distinguish from each other because of their close inter-relationships including:

2.1.1.1 Hardware

Mainframes, workstations, peripheral, connecting networks.

2.1.1.2 Software

Operating systems, utilities, application programs, specialized code.

2.1.1.3 Physical Surroundings

Buildings also influence and embody social rules, and their design can affect the ways that a technology is used.

2.1.1.4 People

Individuals, groups, roles (support, training, management, line personnel, engineer, etc.), agencies.

2.1.1.5 Procedures

Both official and actual, management models, reporting relationships, documentation requirements, data flow, rules & norms.

2.1.1.6 Laws and Regulations

These also are procedures like those above, but they carry special societal sanctions if the violators are caught. They might be laws regarding the protection of privacy, or regulations about the testing of chips in military use. These societal laws and regulations might be in conflict with internal procedures and rules.

2.1.1.7 Data and Data Structures

What data are collected, how they are archived, to whom they are made available, and the formats in which they are stored are all decisions that go into the design of a socio-technical system.

STS represent an interpretive process made possible by optimizing the "goodness of fit" between technology and human systems. Multi-factor analysis suggests that by maximizing the degree of self-regulation, work group productivity and job satisfaction will be consistently higher. Thus, socio-technical systems create the organizational context for knowledge sharing, learning and innovation enabling work groups to think and learn collaboratively thereby, develop original work patterns, maintain flexibility and competitive advantage (Aldridge, 2004)

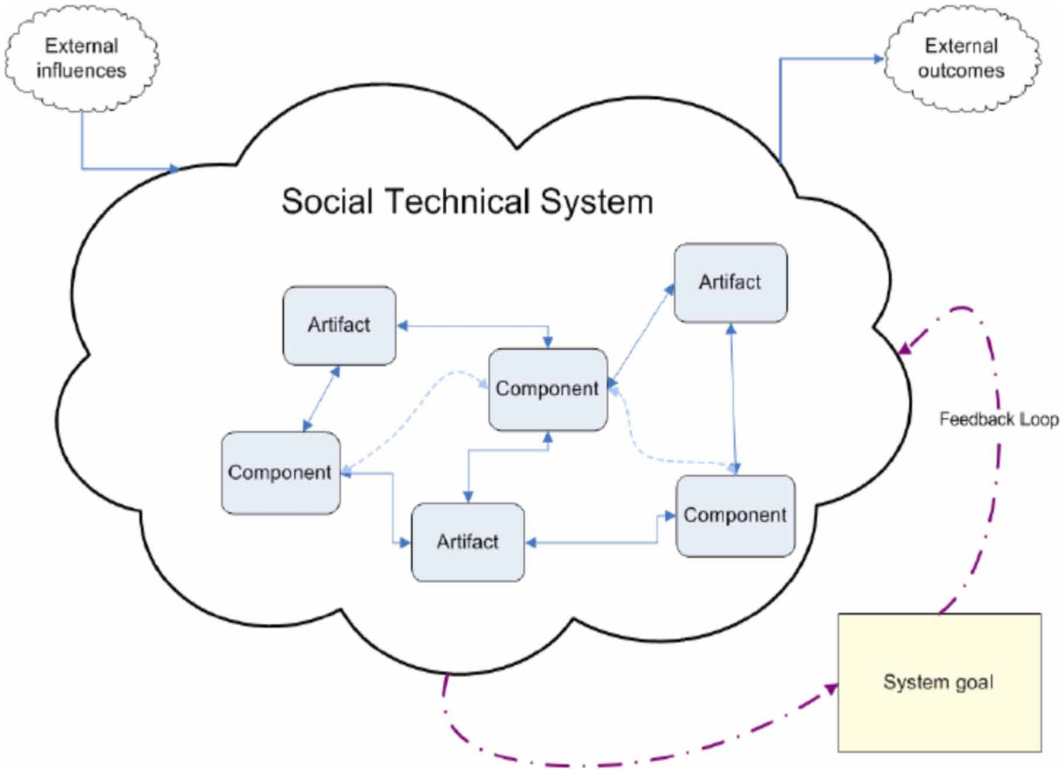
When the sub-components of each component and their interrelationships were taken into consideration, it was realised that both the global technological, economic, and social meta-system and related sub-systems were complex systems. All three components of the meta-system (i.e. technical, economy, and society) and most of the sub-systems of these components (e.g. economic processes, market operations, individual people, companies, etc.) are classified under a special category of complex systems, terminologically known as complex adaptive systems. The distinguishing feature of this type of complex systems is that 'they interact with their environment and change in response to a change' (Clayton & Radcliffe, 1996), that is, they co-evolve.

The concept of STS emerged from the studies undertaken by the Tavistock Institute, London especially during the post-war remobile services provision of industry (Trist, 1981; Cartelli, 2007). Cartelli (2007) reported that the emergence of this concept is highly necessary in pursuit of a fit between the work force and machine during the introduction of technological systems for work automation when it was found out those workers are resistant to technological innovation. Since then, the concept has come into luminance. This concept has been previously discussed by Oladokun et al. (2012a) and a brief description of it is given based on the account of Walker, et al. (2008). STS as a concept is founded on two main principles. The first one is the interaction between the social and technical sub-systems that set the conditions for successful (or unsuccessful) system performance. They argued that the interactions are comprised partly of linear "cause and effect" relationships, the relationships that are normally "designed", and partly from "non-linear", complex, even unpredictable relationships, which are those that are often unexpected. Soft, which is socio, does not necessarily behave like the hard, which is technical (Walker, et al., 2008). That is, people are not machines. They further mentioned that with growing complexity and interdependence that the "technical" can start to exhibit non-linear behaviour. STS as a methodology of systems-based approach of scientific inquiry is then used to handle this kind of complexity. The second of the two main principles, is that "optimisation" of the two sub-systems must be sought. That is, the need for 'joint optimisation' of the two sub-systems. Dwyer (2011), however, used a generic model to illustrate this concept of as shown in Figure 2.

The Dwyer (2011) generic model was used to relate the problem under investigation, the social systems and how it relates to the environment is shown in Figure 14. It is comprised of interplay between various variables including behavioral variables and the environment and also economic variables and policy/regulations variables. All of these works together as a system in order to develop the dynamic of mobile phones and economic growth systems.

In this connection, the developed model proposes a structural model that traverses from the micro-level demand for and supply of mobile phone services to aggregate changes in mobile penetration and the macro production function in which GDP is determined by traditional inputs including capital (net of mobile), and labor stock. There is no attempt to provide a general explanation of the determinants of national output. Rather, a macro production function approach that relates inputs to output is used. We endogenize mobile investment. The causal model we develop as seen in figure 18 demonstrates various relationships between mobile penetration and growth, factors that determine the demand for and supply of mobile services, and those that influence the change in mobile penetration.

Figure 2. A model of a socio-technical system (Dwyer, 2011)



3. A BRIEF DESCRIPTION OF SYSTEM DYNAMICS METHODOLOGY

3.1 System Dynamics Process

A system dynamics (SD) study adopts the case study research design; it aims to do an in-depth elucidation of one entity – the system in focus. The SD modelling process involves conceptualization and quantification of the phenomena underlying the problem behaviour. Although, the SD process is somewhat iterative, it has distinct phases. According to Coyle (1996), Forrester (1991) and Pidd (1988) the process entails the following stages: -

1. Identification of the problem
2. Development of a dynamic hypothesis explaining the cause of the problem – drawing influence diagrams, either as causal-loop diagrams or level-rate diagrams
3. Qualitative analysis of the problem examining what the participants in the system feel is the problem with the system and establishing whether any bright ideas on the system can be borrowed from the modeller's previous experience with similar systems
4. Building a computer simulation model of the system at the root of the problem drawing detailed influence diagram(s) using computer code and formulating necessary difference equations
5. Testing the model to be certain that it reproduces the behaviour observed in the real world
6. Devising and testing in the model, alternative policies that alleviate the problem
7. Implementing the solution recommended

The process is similar to the case study process of an analytical (i.e. un-systems like) approach to problem investigation. However, the details conceptualization and quantification of the variables are a complete paradigm shift from the analytical approach. If applied to an industry, the SD modelling procedures are likely to capture more variables than those that have hitherto been captured in econometric modelling. SD modelling of mobile activity is therefore expected to add significantly to the insight regression modelling has so far given regarding the mobile activity cycles.

An SD study need not cover all the seven stages listed above. "The problem is sometimes solved at stage 3[qualitative analysis], and there is no need to go on to the other stages," (Coyle, 1996) except, of course, the last one i.e. the implementation of the solution recommended by the qualitative analysis.

At the qualitative analysis stage, great insight may gain by a comparing the pattern of the problem behaviour with generic patterns of similar systems, technically known as system archetypes. From Braun (2002) and Senge (1990), eleven system archetypes are explained as follows:

1. **Balancing Process with a Delay:** A person, group, or organization acting towards a goal adjusts their behavior in response to delayed feedback. If they are not conscious of the delay, they end up taking more corrective action than needed, or (sometimes) just giving up because they cannot see that any progress is being made.
2. **Shifting the Burden:** A problem symptom can be resolved either by using a symptomatic solution or applying a fundamental solution. Once a symptomatic solution is used, it alleviates the problem symptom and reduces pressure to implement a fundamental solution, a side effect that undermines fundamental solutions.
3. **Eroding Goals:** A gap between a goal and an actual condition can be resolved in two ways: by taking corrective action to achieve the goal, or by lowering the goal. When there is a gap between a goal and a condition, the goal is lowered to close the gap. Over time, lowering the goal will deteriorate performance.
4. **Escalation:** This archetype occurs when one party's actions are perceived by another party to be a threat, and the second party responds in a similar manner, further increasing the threat. The two balancing loops will create a reinforcing figure-8 effect, resulting in threatening actions by both parties that grow exponentially over time.
5. **Success to the Successful:** If one person or group (A) is given more resources than another equally capable group (B), A has a higher likelihood of succeeding. A's initial success justifies devoting more resources to A, further widening the performance gap between the two groups over time.
6. **Tragedy of the Commons:** This archetype identifies the causal connections between individual actions and the collective results (in a closed system). If the total usage of a common resource becomes too great for the system to support, the commons will become overloaded or depleted and everyone will experience diminished benefits.
7. **Fixes that Fail:** A quick-fix solution can have unintended consequences that exacerbate the problem. The problem symptom will diminish for a short while and then return to its previous level, or become even worse over time.
8. **Limits to Growth:** A reinforcing process of accelerating growth (or expansion) will encounter a balancing process as the limit of that system is approached. Continuing efforts will produce diminishing returns as one approaches the limits.
9. **Growth and Under-Investment:** This applies when growth approaches a limit that can be overcome if capacity investments are made. If a system is stretched beyond its limit, it will compensate by lowering performance standards, which reduces the perceived need for investment. It also leads to lower performance, which further justifies underinvestment over time.
10. **Accidental Adversaries:** When teams or parties in a working relationship misinterpret the actions of each other because of misunderstandings, unrealistic expectations or performance problems, suspicion and mistrust erode the relationship. If mental models fueling the deteriorating relationship are not challenged, all parties may lose the benefits of their synergy.

11. **Attractiveness Principle:** The result sought by a firm and which is the target of a growing action may be subject to multiple slowing actions, each of which represent an opportunity and an opportunity cost to managers. Insight into the interdependencies between the slowing actions is a critical insight into deciding how scarce resources should be utilized to reduce or remove the slowing actions.

The archetypes eroding goals, limits to growth goals and growth and under investment are very core to the problem of mobile output variations and growth. The archetype examples include occurrences that are not alien to mobile firms or industries, implying that some insight into the behaviour of the mobile industry as a whole (or its parts) can be gained from examining the relevant system archetypes.

4. MODEL DESCRIPTION

4.1 Casual Loop and Stock Flow Diagrams for Mobile Phone Service

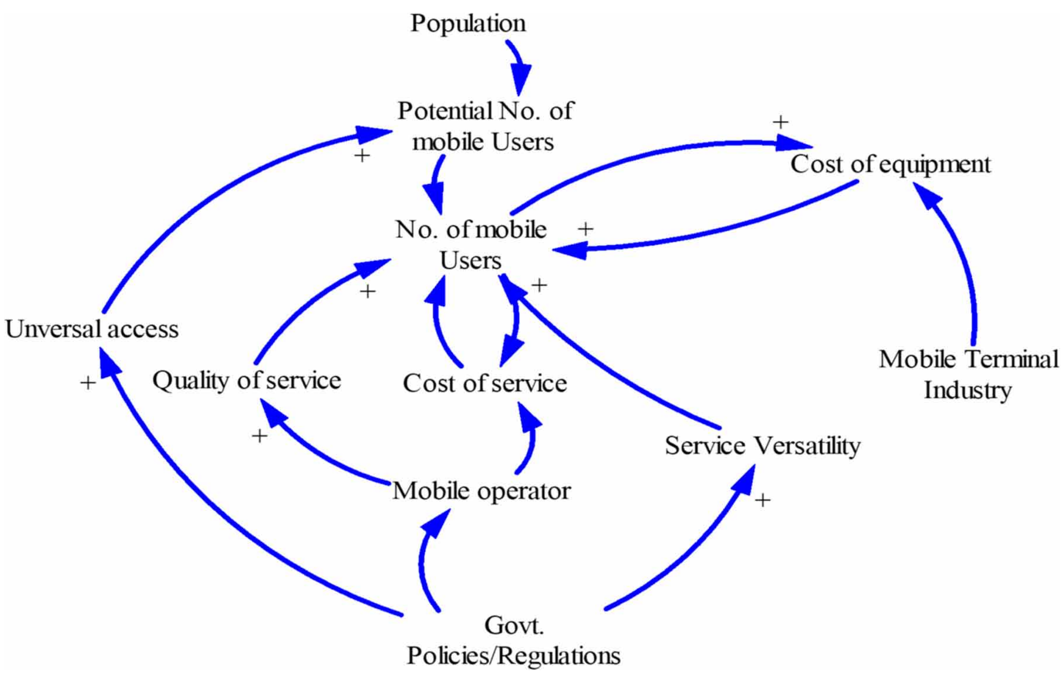
In this section of research, we develop casual loop diagrams for the mobile phone penetration in Kenya, taking the various stakeholders and factors that will be affected by and affect the system into consideration as outlined. The causal loop diagram for the mobile phone industry is shown in Figure 3. To get an integrated view of the model, we start with the main variable-number of mobile users which represents the subscribers of the basic telecommunication services. Households subscribe to telecom services. An increase in the number of households leads to increase in the number of subscribers and depletes the potential subscribers. This bi-directional relationship forms a loop with negative polarity i.e. negative feedback loop. An increase in economic growth increases the income level of the people and hence the subscriber base for telecommunication services. As the number of subscribers of a telecommunication services increases, the amount of information traffic and frequency of request for connection establishment increase. This causes congestion, which deteriorates network performance. However, if the service provider synchronizes the infrastructural build-up i.e. setting up of switches, access loops and trunks, with the pace of building up of subscriber base, congestion reduces.

Quality of the access loop decides the type of services; a service provider can provide what subscriber has subscribed for. Economically, the access loop cost is one of the major components of total infrastructure cost of telecommunication services. Hence, as the quality of access loop improves, the variety of services being provided increases as well as the cost of services. Increase in cost of providing service enhances the price of subscription of the service, which in turn shows its negative effect on subscriber level based on their price elasticity of demand for services. The price for services gets lowered with increase in industry experience, service providers experience and economy of scale. Variety of services is not only governed by the quality of access loop but by the threat of competition also. If there is no expected competition in the market place, then monopolists do not feel motivated to provide higher quality services even though the access loop is capable of supporting such services. Similarly, even with high threat of competition, the service provider may not be able to provide multiple services immediately because of the low quality of the access loop. Similarly, threat level of competition and variety of services both dictate the time for deployment of services. From a high-level perspective, the causal loop diagram for mobile industry is depicted in Figure 3.

Techno-economic simulations were used to replicate the conditions of the telecommunications technology and its environment so that growth of the services could be investigated and monitored by researchers, planners and managers. Technical parameters such as network bandwidth, quality of service and economic parameters such as sales, subscriber forecasts and revenue projection were simulated using techno-economic models.

The techno-economic model encapsulated technical, economic, social, political, competition and infrastructural aspects, which were relevant in providing service. (Song, 2001) highlighted the

Figure 3: Causal loop diagram for the mobile phone service



supply side cost parameters of telecom service provisioning such as facility investment, area/non-area specific investment and quality related investments etc. (Chatterjee, 1998) stressed that the demand for services varied based upon certain socio-economic (house hold income, profession) and demographic factors (educational level, age, family size, population density, location). Other economic forces that could influence the demand are the price of service (Cocchi, 1992), quality of service (Dutta, 2001) and competition (Sice, 2000).

A system dynamics model of the existing structure of mobile service provision process of Kenya was conceptualized in terms of various variables of a system dynamics model as shown in figure 4 and also a stock and flow diagram with equations is shown in figure 5. The model variables comprise: 4 levels, 6 auxiliaries, 4 constants and 5 rates. Technical meanings of these variables in system dynamics are explained. The variables are defined and their relationships explained. The build-up of the system dynamics model is described. This can be expounded as follows in a stocks and flow diagram

4.2 Causal Loop Diagram (CLD) for ICT Technology Interaction

In our sub model there are three main positive feedback loops driving the diffusion of technology (Figure 6). On the knowledge base side investment in the technology start-ups increases the specialized business needs and lowers the cost of the technology through mechanisms such as economies of scale in production and learning by doing.

On the entrepreneur's side growth in the adoption of technology by government will reduce the uncertainty of its merits and generate benefits for users by lowering their hesitation in adopting the new technology. Moreover, as technology is being more adopted by the users, they gain experience in using the technology and this eventually results in decreasing the uncertainties about the new technology. Hence, technology provides users with a greater value and, consequently, encourage more users to adopt the technology. Thus, as the technology diffuses into the market, users' attitude in favour of the technology will increase and it gains legitimacy

Figure 4. Mobile phone service; stock & Flow diagram for the mobile phone service

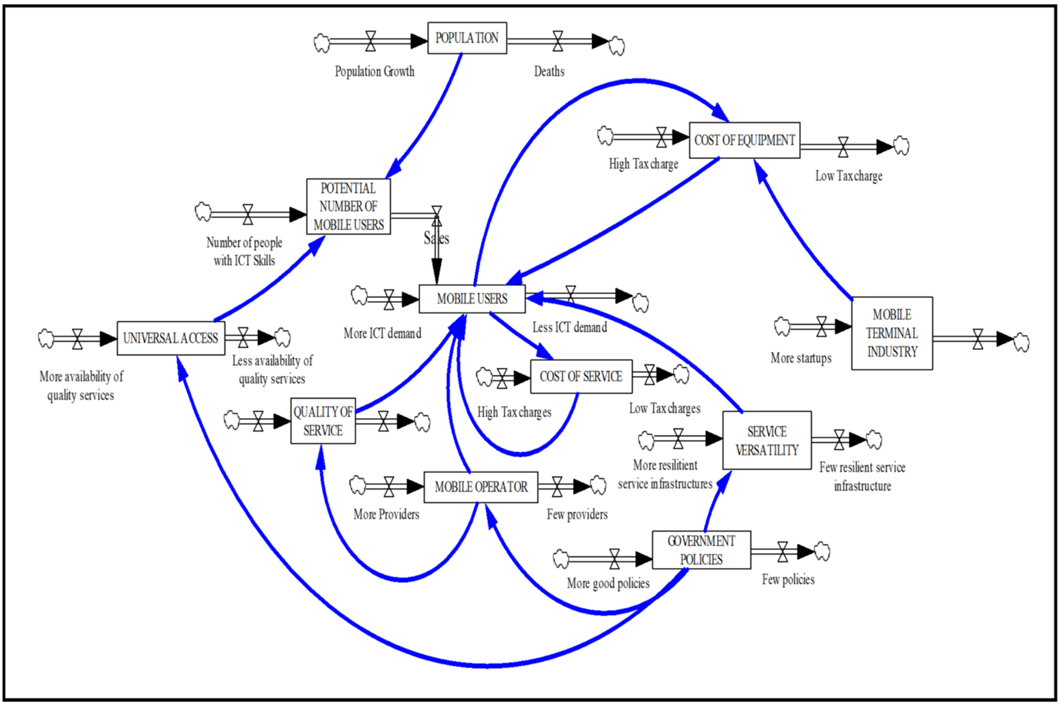
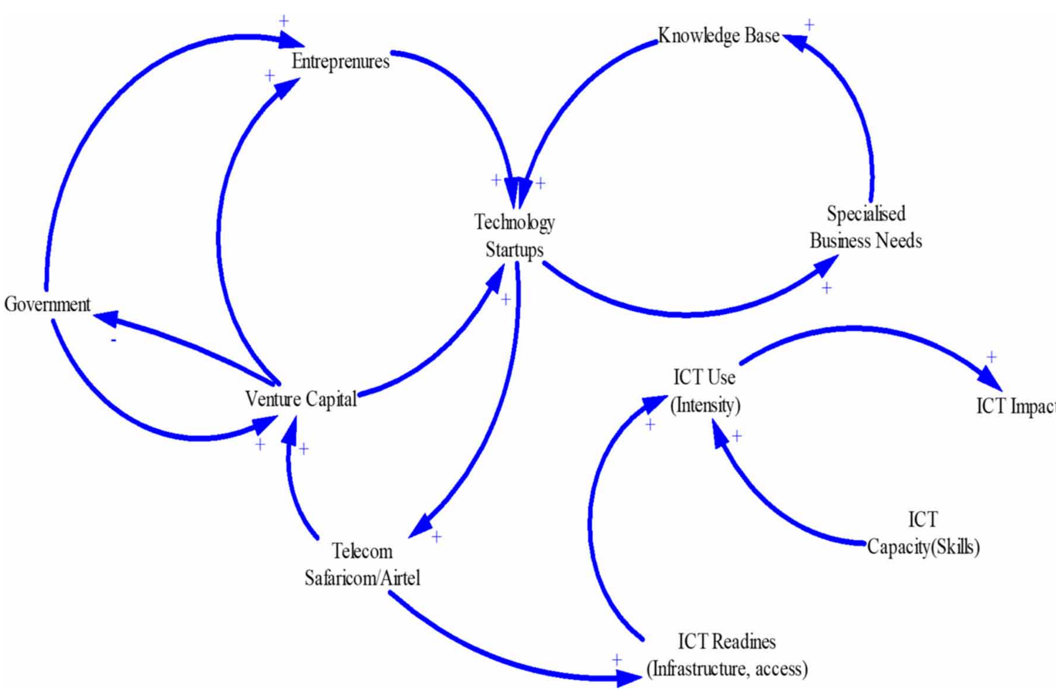


Figure 5. Mobile phone service Stock & Flow diagram with equations



As the technology diffuse the venture capitalist increase in size as well as political strength and may influence the regulatory frame work in favour of the technology. As more adoption takes place, more institutional adaptation will occur.

When a technology diffuses in to the market, there are several positive feedback mechanisms that contribute to its growth. The loop indicated as "telecom, venture capital and technology start-up" shows that when the venture capital increases, the repetition of technology start-ups, which is measured as cumulative production, will increase and improve the telecom usage methods.

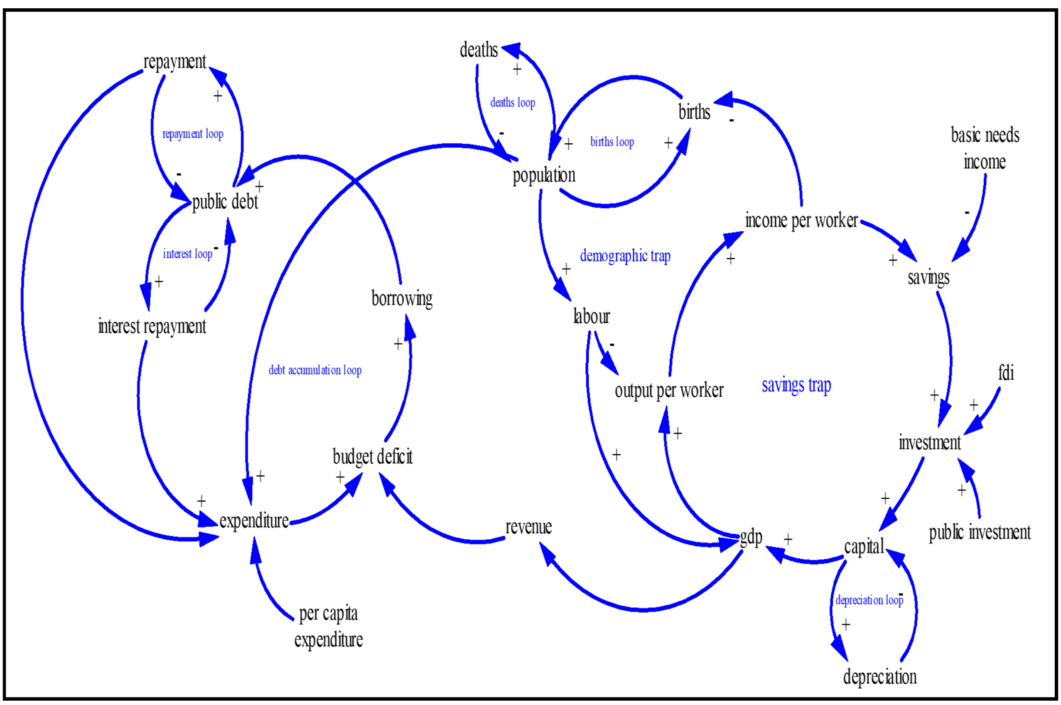
ICT readiness (infrastructure and access) is increased by repeating the telecom use process or as the accumulated production of the technology increases. Additionally, new improved processes will be adopted and it changes the access methods. Hence more ICT readiness leads to more ICT use and more ICT impact. Thus, eventually requiring better ICT capacity or skill attracting more users to adopt the technology.

4.3 Causal Loop Diagram for Society and Economy

4.3.1 Debt Accumulation

The debt accumulation process is embodied in the feedback loops (debt accumulation loop, repayment loop, and interest loop) as shown in figure 7. Public debt increases through borrowing and interest accrual. As debt increases, debt servicing consisting of repayment of principal and interest payments, rises which consequently increases government expenditure. As government expenditure build up without corresponding increase in revenue, budget deficit increases which create the need for more borrowing the next year-round. The counteracting loop (repayment loop) and (interest loop) strives to counteract the growth of public debt. Thus, as public debt increases, repayment of principal and interest payments increases which then reduces the stock of public debt outstanding.

Figure 6. The Causal Loop Diagram for the Kenyan technology sectors interaction



4.3.2 Poverty Trap Mechanism

The poverty trap mechanism is represented by the interaction of the savings trap and demographic trap. The conceptual framework of the savings traps is the accelerator principle which posits that investment is a function of rate of change of income. The causal structure of the savings traps and demographic traps are described as follows:

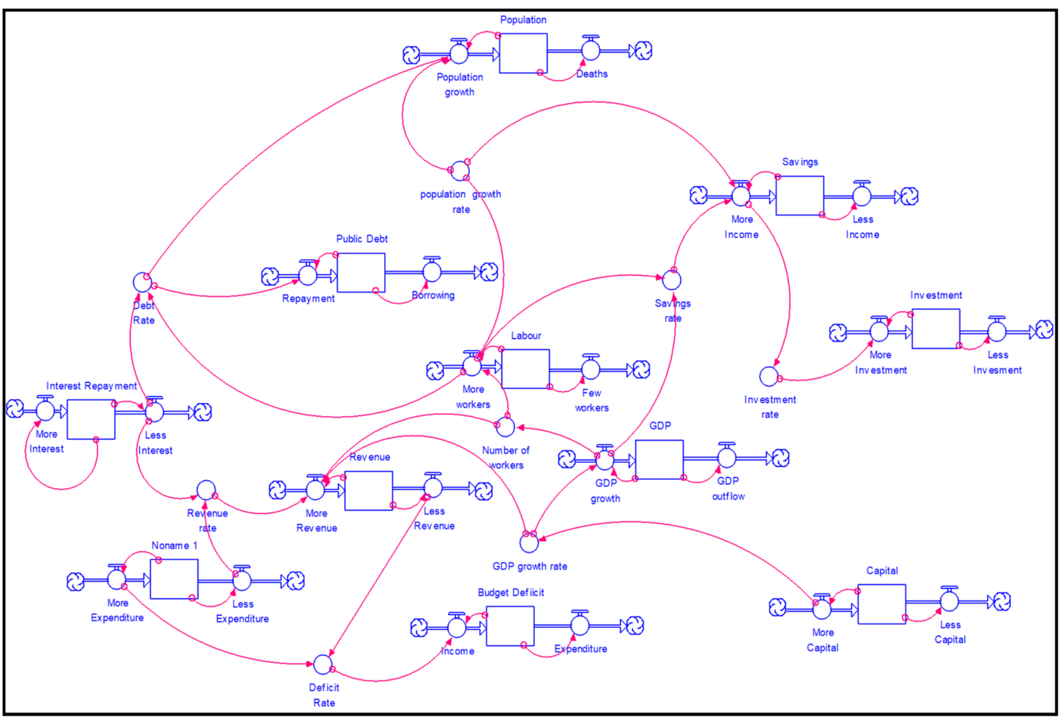
4.3.3 Savings Trap

The conceptual framework of the savings traps is the accelerator principle which posits that investment is a function of rate of change of income. In poor countries, savings rate can be become very low or even negative when income is low, because impoverished households use all of their income in the struggle to just stay alive (Sachs et al., 2004). Once basic needs, i.e. personal health, food intake and shelter are met; poor households may save some of the excess income (Sachs, 2002). The causal loop (savings trap) demonstrates that low income per worker causes low savings which then decreases investment and capital accumulation. Consequently, output per worker is expected to decrease due to low capital accumulation coupled with high population growth. As output per worker decreases over time, income per worker decreases as well, which causes low savings the next year-round.

4.3.4 Demographic Trap

The demographic trap shows how high population growth, with low capital can push a country into the poverty trap. Based on the assumption that poor countries are characterized by low income, it is proven that high fertility rates in the world are observed among the world's poorest people. With low income per worker, it is expected that fertility rate will increase causing birth rate to rise. As birth increases, population increases. Population growth causes new entrants to the labor market to increase, which consequently, increases employment, resulting in the decline of capital-labor ratio. In

Figure 7. Causal loop diagram for society and the economy



the absence of technological improvement, which is expected to be the case in poor countries, output per worker will decline. As a result, income per worker will decrease causing population to grow. It is important to note that as the demographic trap loop becomes stronger over time, it strengthens the savings trap which then reduces investment and capital accumulation further. The strength of the demographic trap can only be counteracted by the deaths loop, when death surpasses birth to slow the growth of the population. The SFDs representing the society and economy interactions are shown in figure 8 and 9

4.4 The Equations for the Society and Economy Sub-Model

4.4.1 Population

The population sector model's total population in a simplistic way. The growth of population is determined by the relation between births rates and deaths rates (Meadows, Randers *et al*. 1972; Szirmai 2005). Here, "births rate" and "deaths rate" are measured in people per year. They represent the total rate at which population is being increased and decreased. The population is represented in the model as:

$$p_t = p_{(t-1)} + (dt)\, br_{(t-1)} - (dt)\, dr_{(t-1)} \tag{1}$$

Here p_t is the current population, $p_{(t-1)}$ *is* the previous year population, $br_{(t-1)}$ is the births rate and $dr_{(t-1)}$ is the deaths rate.

Births rate is determined by births rate normal *brn*, effect of per capita income on births ($f(in)$) and previous year population $p_{(t-1)}$. The births rate is called "normal" rate because they correspond to a standard set of conditions at the initial model setting. However, it is expected that income change will

Figure 8. Stock and flow diagram for society and the economy

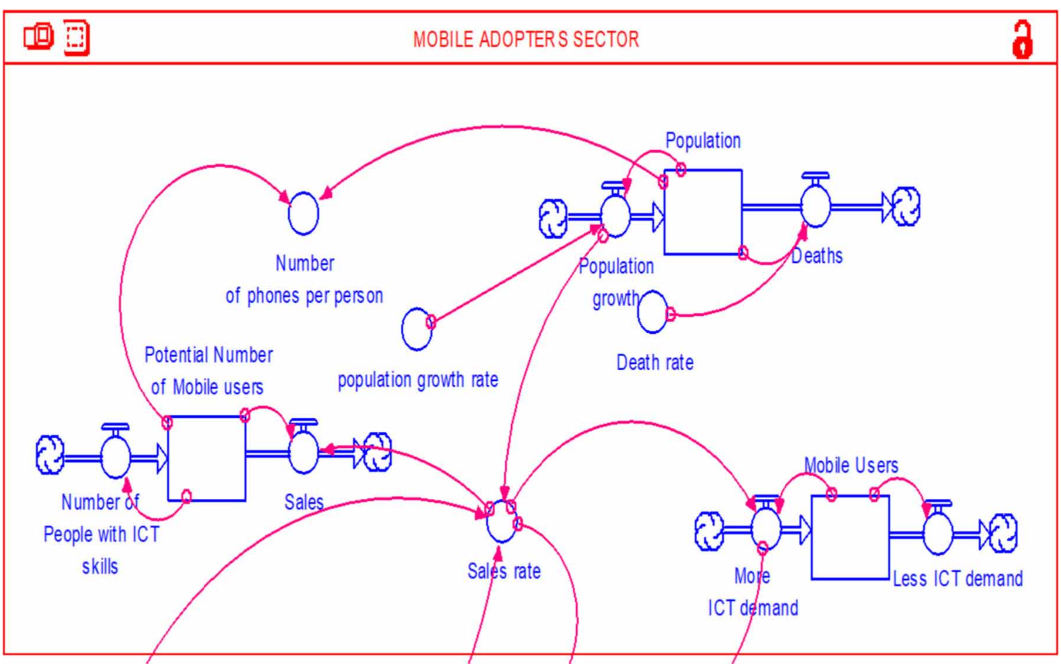


Figure 9. Stock and flow diagram for society and the economy with equations

cause births rate to rise or fall from their normal values. We assumed generally a negative relationship between per capita income and births rate. The equation representing births is:

$$br_t = \left[brn * f\left(in_{(t-1)}\right)\right] * p_{(t-1)} \tag{2}$$

Deaths rate is a function of deaths rate normal (drn_t) and population. The equation representing deaths rate is:

$$dr_t = drn_t * p_{(t-1)} \tag{3}$$

The labor force in the population module is a function of population and working age population fraction. We assume that labor force equals employment. The equation representing labor force is:

$$l_t = w_{(f-1)} * p_{(t-1)} \tag{4}$$

4.4.2 Production

The production sector employs Cobb-Douglas production function to represent output. Output depends on factors of production (capital[2] and labor force) and productivity. The Cobb-Douglas production function is represented as:

$$y_t = k_{(t-1)}^{\alpha} * \left(dt\right) l_{(t-1)}^{(1-\alpha)} * a_{(t-1)} \tag{5}$$

Here, y_t is the production, $k_{(t-1)}$ is the previous year capital, α is the capital elasticity, $l_{(t-1)}$ is the previous year labor force and $a_{(t-1)}$ is the previous year productivity.

In the production module, capital accumulates through capital acquisition and capital depreciation. Capital acquisition depends on investment. Investment consists of domestic private investment, public investment and foreign direct investment. Capital depreciation is based on perpetual inventory estimation with a common geometric depreciation rate of 4% is assumed which gives an average life of capital of 25years. The capital accumulation equation is represented as:

$$k_t = k_{(t-1)} \left(1 - d_k\right) + \left(dt\right) ck_t \tag{6}$$

Here, k_t is current capital $k_{(t-1)}$ is the previous year capital, d_k, is annual depreciation rate of capital and ck_t is capital acquisition.

In the sub model, public investment is determined by government decision on public expenditure pattern, i.e. the decision to either invest or consume. Foreign direct investment is an exogenous variable from historical data which is an indication of the attractiveness of the local economy to foreign investors. However, savings is determined in the model based on the assumption that: Households require a level of minimum real consumption *c* to meet basic needs of personal health, food intake and shelter. When income *n* is above *c*, the household saves a constant fraction *(f)* of the excess *(n-c)*. When income is below *c*, household savings is zero, as household consumes as much income as possible in order to come as close as possible to meeting basic needs (Sachs, 2002; Sachs et al., 2004). Thus, savings *s* is represented as:

$$s = \begin{cases} 0 & if\, n < c \\ \varnothing\left(n - c\right) & if\, n \geq c \end{cases} \tag{7}$$

4.4.3 Public Debt

The public debt model demonstrates transparently the mechanisms that generate public debt. We assume that government finances its budget deficit by borrowing and depict it as a result of a government budget constraint:

$$pd_t + i_t d_{(t-1)} + \frac{d_{(t-1)}}{m} = bd_t = gb_t \tag{8}$$

Where pd_t is primary deficit, $_{it}$ is the interest rate, $d_{(t-1)}$ is the public debt of the previous year, *m* is the debt maturity, bd_t is the budget deficit, gb_t is the borrowing.

We express the stock of total public debt d_t from the government budget constraint equation and the public debt model as follows:

$$d_t = \left[d_{(t-1)} + \left(dt\right) gb_t - \left(dt\right) \left(\frac{d_{(t-1)}}{m} \right) \right] + [ai_{(t-1)} + \left(dt\right) ia_t - \left(dt\right) is_t \tag{9}$$

Here $ai_{(t-1)}$ is accrued interest of the previous year, $(dt)ia_t$ is the interest accrual, and $(dt)is_t$ is interest elimination.

The public debt model adopted the ‘co-flow structure’ (Sterman, 2000) to account for ‘accrued interest’. As government borrows, it attracts an interest obligation, which is referred to as ‘interest accrual’. The ‘interest accrual’ is stored into a stock of ‘accrued interest’. ‘Accrued interest’ represent the total interest to be serviced per year. On the other hand, when repayment on debt is made, it decreases ‘accrued interest’ through ‘interest elimination’. In sum, the co-flow structure helps us to keep track of ‘accrued interest’ as an attribute of public debt.

5. SIMULATION RESULTS AND ANALYSIS

Problems that cannot be solved analytically given the complexities and non-linearity find answers in simulation. It helps uncover and explain complex relationships between control policies and business processes (Zhang, 2004). It critical for organizations and their processes to have the abilities, both at design and operation level to be responsive to different configurations to be tested against different realizations of future scenarios.

The integrated model framework and its test presented in this part has proven to be suitable to be extended for distributed simulation and thus supporting large-scale, complex analysis and design of integrative innovation model. In addition, as most of the information has been taken from the prevailing scenario of the mobile industry sector to simulate the model behavior, it lends extra credibility and confidence in making future projections. In the present section, we discuss the simulation results performed on the base model together with some scenario projections. The base numerical simulation has been performed with parameters that have been set-up for the period 2005-2030. In the following paragraphs, we describe the flow of the simulation.

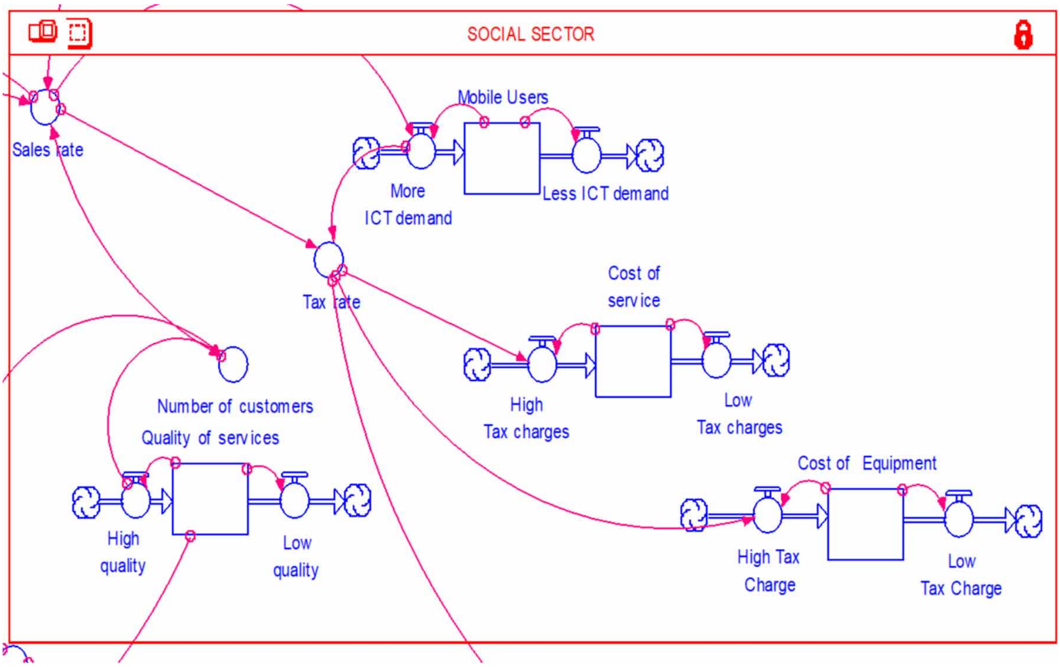
5.1 Technology Sector Dynamics

In the mobile adopters Sector (Figure 10), a chain of interactions between Population and the linking sectors has been simulated and one can observe how the feedforward-feedback pulses propagate smoothly through the chosen time-path creating asynchronized pattern of behavior as shown in Simulation Graph in figure 11.

From the subscriber perspective, the number of potential mobile subscribers is projected to move towards stagnation starting from year 2020 onwards, showing a substantial decline in the aggregate number of potential subscribers, By the year 2020, the mobile subscribers in Kenya is projected to reach up to 40 million users covering approx. 87% of total Kenyan population. In the next five-year period i.e. 2020-2025, though, an extra 5 million new customers are projected to join in, remarkably reduced compared to more than 10 million new subscribers adding up every year during the period Year 2015-2020. However, the absolute number of potential subscribers will keep on moving, albeit at a very slow rate, on account of increasing population (market potential projected to grow at CAGR 1.8). Inclusion of incremental population trend of a country and its ensuing effect over the number of subscribers is a remarkable creative departure of our model from other developed mobile or telecom models. It is important to note that when we use the estimated GAGR value of user’s growth in Kenya (i.e. CAGR 20%) estimated by CAK and the other agencies, in place of historical coefficient values, we arrive at approximate similar estimate (i.e. 40 million subscribers by 2030).

In this module, one can also notice positive feedback loops between Potential number of mobile users, mobile users, and sales rate. However, as one moves along the mobile users path, the respective stock values of potential mobile users diminish as shown in figure 11 indicating a negative feedback loop at work.

Figure 10. Mobile adopters sector; stock and flow diagram



5.2 Social Sector Dynamics

Moving to the social sector (Figure 12), we find the proportionate increment in the mobile market share holding respectively a differential but steeping growth curve of mobile market share initially before flattening out due to stagnation in mobile user's volume. It also creates a negative feedback impact over the quality of services which has an exponential growth slope as it represents accumulated number of subscribers over a period of time. This has also occurred due to a positive causal effect of market feedback to the total number of mobile users at a given point of time.

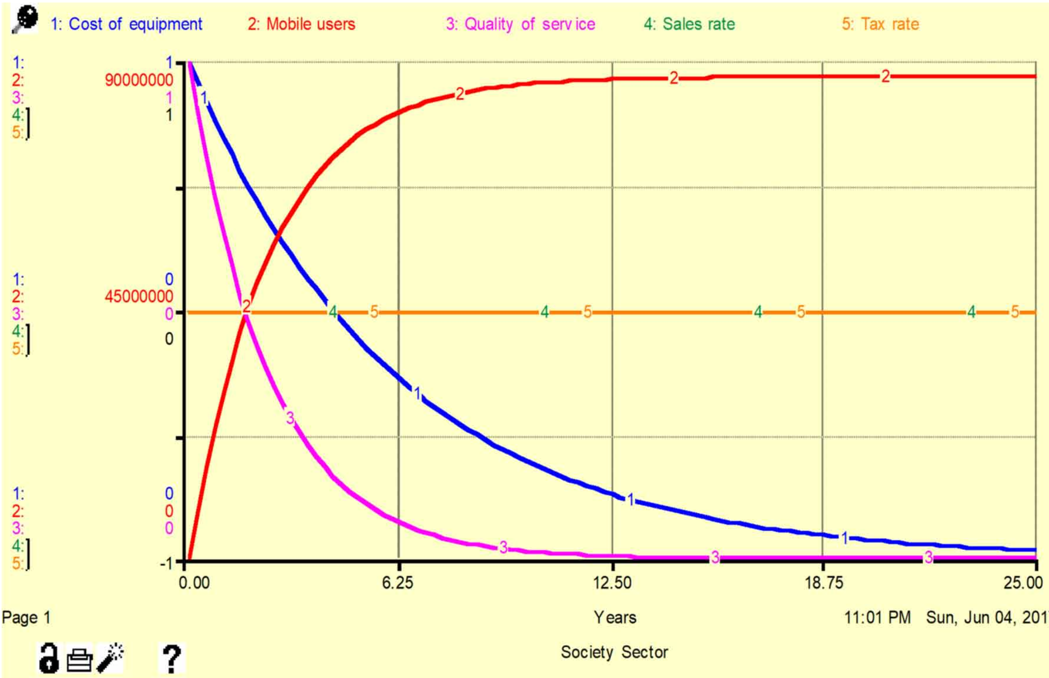
This market dynamics has also been collaborated with cumulatively increasing market share of leading mobile operator in Kenya having a positive effect on cost of service and equipment. This is shown in Figure 13, Graph of social sector.

6. CONCLUSION

There are many academics that will argue that technology is (at present) the most important force driving social change. This does not mean that social, cultural, political, and economic factors do not shape technology. It is not that technology shapes itself, but technologies complement each other, or depend upon one another, especially when we are dealing with general purpose technologies (GPTs), which are highly pervasive of the whole economy and society.

It is easy to fall into 'quasi' technological determinist stand-points when looking at major changes experienced by a society or a group of countries during long periods of time. These types of studies provide a big picture, an economic historical perspective, overlooking the 'people' behind the creation of specific technologies. In these cases, it is common to encounter terms such as technological trajectories, techno-economic paradigms, technological regimes, and technology systems, which give the erroneous idea of being technological determinist. What they mean is that technologies build one upon the other, they form 'clusters' of technologies, and each regime or paradigm characterize an

Figure 11. Graph of mobile adopters sector



economic era, and is dominated by one or more GPTs or enabling technologies. The replacement of an all pervasive GPT alters the paradigm. These analyses, based on economic and historical accounts, are much better at explaining how technologies develop and produce changes in societies, and as such, they are more adequate and robust theories of technology.

This research has attempted to propose a modelling approach for the investigation of mobile phone usage or telecommunications services and its impact on society in Kenya. The developed models incorporated the integrative modular framework of generating causal dynamics prevalent in the telecom sector also successfully acquires the capability of short-mid-long-term forecasting. It discards the notion that holistic modelling brings into 'coarseness' in the modelling and therefore cannot be applied for future projections. It proves that if the causality of model variables can be founded upon a robust model with the support of conceptual and quantitative information, one can succeed to capture the dynamics of any system in a comprehensive way.

As can be seen here, the modelling was primarily first done based on the conceptual insight drawn through an extensive literature survey and thereafter it was put to further refinement, customization and validation taking a case study of Kenyan telecom market. The novelty of this kind of modelling approach is that, the generic framework used here suits to adapt to any socioeconomic situation and be able to incorporate, substitute or modify any number of system variables or values.

Observations made in this study have three major implications for theory in mobile services provision and the society, and for theory in governance. The observation that there is need for regulation of response of the mobile industry to changes in mobile services provision demand implies that the industry as a whole need to be managed the way a business corporation is managed. Generally, a mobile industry is not viewed as a 'managed system' the way a corporation is viewed; the industry is therefore managed collectively and simultaneously by all the players in it i.e. the society. This leads to the prisoner's dilemma, whereby bright individual strategies result in collective folly. Efficient mobile services provision management at project (and firm level) should be supported by efficient mobile

Figure 12. Social sector; stock and flow diagram

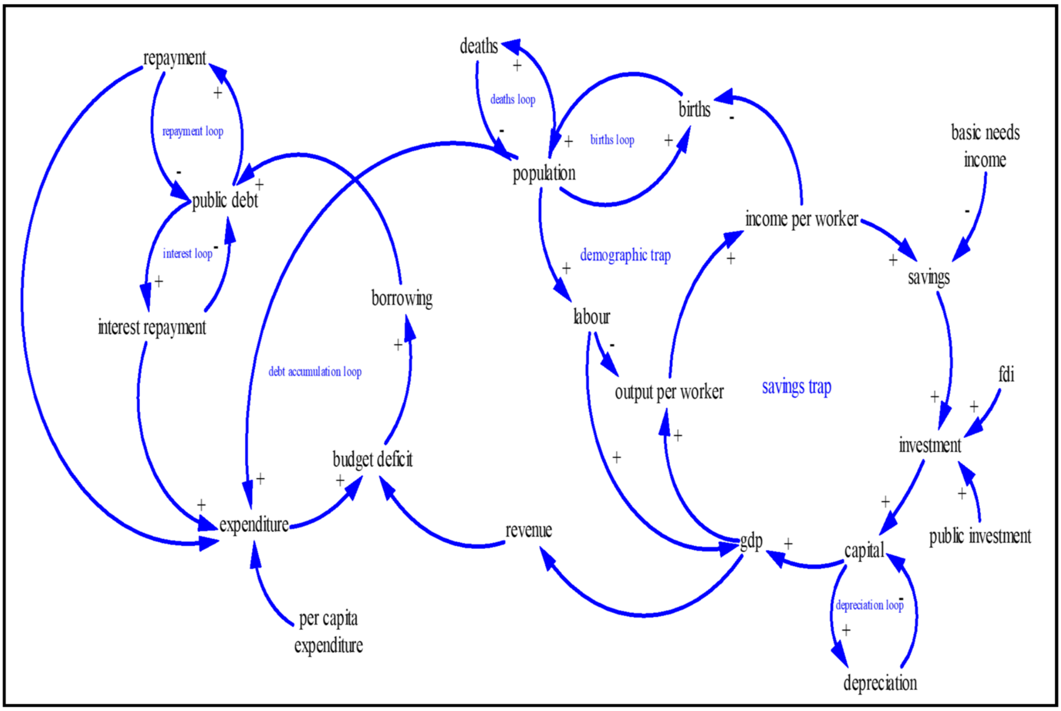
System Archetype	Dynamic Theory	Examples
Eroding Goals	The initial amount is greater than the goal, when followed over time; the initial amount may diminish to gradually approach the goal.	In the initial state, the number of mobile operators was five; this was greater than the stated goal. Following over the years, the number of operators decreased to Three. The three leading operators have co-existed in the Kenyan's mobile market to reach a considerate degree of stability since 2010.
Limits to growth.	The 'limits to growth' archetype states that a reinforcing process of accelerating growth will encounter a balancing process as the growth limitation then a system is approached. When the limits to growth are approached, the growth engine begins to lose its effectiveness and the rate of growth begins to flatten.	The number of mobile+ subscribers in Kenya gives an indication of how vibrant the telecommunication sector is. It also shows the rate of growth of the sector. It helps determine companies stage of growth and respond strategically to the different challenges that come with each stage. The market share for each player in this field can also be determined using this very important indicator.
Growth and Underinvestment	Applies when growth approaches a limit that can be overcome if capacity investments are made. If a system is stretched beyond its limit, it will compensate by lowering performance standards, which reduces the perceived need for investment. It also leads to lower performance, which further justifies underinvestment over time.	People or firms with grand visions who never realistically assess the time and effort they must put in to achieve their visions.

services provision management at industry level, in order to increase the organizational efficiency of the mobile industry as a whole.

ICT has a critical role in driving the economic, social and political development of Kenya as espoused in Vision 2030. How the country has steered ICT development over the past four or so years to 2017 and beyond will greatly impact on the achievement of the country's Vision 2030. There is a need to align the National ICT Master Plan to the devolution reality and address key challenges that may hinder the ICT sector from playing its rightful role in national development.

Kenya produced its first National ICT Policy in 2006. Its vision is a prosperous ICT-driven Kenyan society, while its mission is to improve the livelihoods of Kenyans by ensuring the availability of accessible, efficient, reliable and affordable ICT services. This policy was guided by the need for infrastructure development, human resource development, stakeholder participation and appropriate policy and regulatory framework. It focuses on IT, broadcasting, telecommunications, postal services, radio frequency spectrum, universal access and institutional framework for implementation. The

Figure 13. Graph of social sector



country has not updated this policy for close to eight years, a period when the world has witnessed various technological developments and many changes have taken place in the ICT sector in Kenya. The policy therefore needs to be up dated to take into account the changes including Vision 2030; the Constitution; new sectoral strategies; and other realities that have emerged since 2006. The ICT State Department developed a draft ICT policy which needs to go through the various stages of policy development and finalised as soon as possible.

The Information and Communications Technology (ICT) Sector Policy Guidelines (September 2014) as reviewed, provided a clear and compelling roadmap that would drive social, economic, cultural and political transformation through the effective use of Information and Communications Technology (ICT) in the years ahead. The Policy complements and builds upon Vision 2030 and provides many of the key strategies essential for achieving Kenya's national development targets in the years ahead.

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