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Technology Diffusion and Inclusive Development in Africa: A System Dynamics Perspective

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***Abstract*—**Technology or lack of it will play an important role in Africa's effort to achieve inclusive development. Although a key determinant of competitiveness, new technology can exacerbate exclusion of the majority from the mainstream economic activities. To minimise potential technology exclusion while leveraging its critical role in African's development, requires insight into technology diffusion process. Using system dynamics approach, a technology diffusion model is presented. The frequency of interaction of people exposed to and those not exposed to technology, and the technology adoption rate - the fraction of people who embrace new technologies once they are exposed, are identified as the broad factors critical to technology diffusion to wider society enabling more people to be part of the economic growth process. Based on simulation results, it is recommends that these two broad factors should form part of national policy aimed at achieving inclusive and sustainable development in Africa.

***Keywords*—**Inclusive Development, System Dynamics, Technology, Technology diffusion.

I. Introduction

THE role of technology in contributing towards economic of growth of a country can be traced as back as 1957 in the works of Solow. Solow calculated the growth in output attributable to change in capital and labour respectively. By totally differentiating the production function, he derived the elasticity of output with respect to capital and labour. Applying a competitive pricing condition, the share of both capital and labour were calculated. Solow's results showed that growth rates in capital and labour could not account for the overall output growth. He attributed "the uncounted for" growth in output to "residual" factors associated with technological change [1].

For predominantly agricultural African, countries technology is important in increasing local value addition of exported products. For many of these countries revenues from exports have been either stagnant or decreasing despite increase in export volumes. For the mineral rich countries, still technology is needed to exploit these resources. As such, policy debate on how to accelerate economic growth and development on the continent and how to make such development inclusive should include the aspect of technology among others.

Despite the critical role of technology in increasing countries' economic growth, it may do so in a way that excludes a segment of society from mainstream economic activities. Technology-driven growth tends to take on board only those that embrace it. Access and adoption of developmental technology by more people in society, therefore, reduces the likelihood of technology exclusion. In order for policy makers on to influence this likelihood, they need to have some insight into the technology diffusion process in their respective countries.

Against this background, this paper presents a technology diffusion model developed using a system dynamics approach. The model makes explicit key factors that are critical to technology diffusion in a society and that can act as leverage policy levers to speed up the diffusion process, hence enabling more people to be part of modern economic growth processes.

The rest of the paper is organised as follows. Section 2 looks at the role of technology in sustainable development. In Section 3 and Section 4, system dynamic methodology used to develop the technology diffusion model and the model itself are presented respectively. Simulations of technology diffusion to society overtime is presented and briefly discussed in section 5. The paper concludes with insights and recommendations.

II. Role of Technology in Sustainable Development

Technology is linked to sustainable development via its impact on competitiveness.

Competitiveness refers to the ability of firms or industries within a country or region to increase in size, market share and profitability through the sale of goods and services. Some have defined it is the degree to which a nation can, under free and fair market conditions, produce goods and services that meet the test of international markets while simultaneously maintaining and expanding the real income of citizens [2]. This definition takes cognisance of the welfare effects of increased productive activities as a country captures bigger market shares. Some other authors have linked the definition of competitiveness with an increase in per capita income and employment. They argue that competitiveness is a product of increased productivity. To achieve it, output per each factor of production, including labour has to increase [3]. Assuming perfect market conditions or at least market conditions that support a positive correlation between reward for factor inputs and productivity, wage rates payable will increase with productivity. Competitiveness will therefore lead to an increase in Gross Domestic Product (GDP) per capita and overall improvement in national welfare.

One cannot talk about competitiveness without technology. Technology is a key determinant of production efficiency and subsequently for competitiveness. Technological advances,

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innovation and competitive advantage are connected in multidimensional relationships [4]. Competitiveness depends on average costs of production. Production costs are a function of price and non-price factors, some of which are the ability to adopt and use new technologies. Sustainable competitiveness depends on the ability of a country to offer comparative products to its competitors at lower prices on an open market. It requires that a country is able to lower its production costs without sacrificing quality. Technology innovation offers one of the most practical ways to reduce production costs while at the same time maintaining or even increasing product quality.

Technology determines the actual value of the physical resource endowment Stumpf & Vermaak [5]. Through its value adding, technology augments the value of a country's resource base and enhances its competitiveness, holding other factors constant. Therefore, there is general agreement that countries seeking to enhance their international competitiveness, have to engage in domestic R&D and subsequent innovative activities.

Based on the Chinese experience, Fan [6] contends that development of innovative capability and self-developed technology are the key factors leading to domestic firms catching up with multinational corporations. She emphasises that domestic firms need to prioritise building innovative capabilities from the beginning in order to withstand competitive pressure from multinational companies as well as other domestic companies.

Ultimately, competitiveness, technology and trade are intertwined. Without competitiveness, trade cannot be sustained, and without technology, long run competitiveness is unlikely. Trade is an implicit indicator of competitiveness and a key determinant of economic growth, while technological progress is subtle indicator of progress toward competitiveness [7].

III. System Dynamics Methodology

System dynamics (SD) is a computer-based methodology for building quantitative and qualitative models of complex situations so that they can be better understood and managed [8]. System dynamics as a unique modelling methodology is strong in increasing understanding of the observed phenomenon, and in establishing consequences of different options available at a decision point [9].

The system dynamics approach is inclined towards refutationism. Refutationism as a way of thinking in the knowledge acquisition debate holds that scientific knowledge consists of conjectures that are refutable, vulnerable to empirical error and that knowledge advancement is achieved through the process of adjusting, or change of mistaken conjectures to overcome refutations [10]. The refutationism approach puts more weight on the thinking process than on data per se. In line with refutationism, the system dynamics field suggests that the first stage of generating knowledge is to think about the issue at hand. The refutation method requires the search for causal explanations, which in turn opens up the opportunity for objective interrogation of the presupposed causal relationships, and in the process new knowledge is created.

System dynamics as a methodology is grounded in control theory and modern theory of nonlinear dynamics. System dynamics is also a practical tool that policy makers can use to help solve important problems [11]. System dynamics provides means by which to capture complex relationships and feedback effects within a set of interrelated activities and processes [12]. Its presentation has a user-friendly interface that encourages non-academics to internalise the logic behind the model. In addition, the approach allows the use of quantitative and qualitative data; hence, it is not limited in its use when quantitative data is unavailable. Specialised software in system dynamics modelling allows scenario simulations, in fairly easy and understandable steps, an aspect critically important in applied research.

Using SD to articulate technology adoption process makes explicit causal and feedback relationships involved and through a simulation process reveals high leverage policy variables that policy makers can use influence the technology adoption process.

IV. System Dynamics Model of Technology Diffusion

The formulation of the model was guided by the systemic relationship in the technology adoption process as first articulated by Bass [13].

First, it is noted that potential adopters of new technology in any country will be a function of a country's population, those that have already adopted the technology at the time of analysis and the rate at which the new technology will be adopted according to equation (1) below:

$$\mathrm{PANT} = \sum \left[(\mathrm{CP} - \mathrm{IA}), \text{-AR} \right] \tag{1}$$

where PANT stands for Potential Adopters of New Technology, CP for Country Population, IA for Initial Adopters and AR for Adoption Rate.

Equation (1) says that holding a country's population constant, the number of potential adopters of new technology will decline overtime as more people migrate to the use of new technologies. The assumption of constant population is a simplification, which is relaxed at later stage of model analysis.

The adoption rate of technology is captured as function of contact rate between those that have already adopted new technology and those that have not. It is further a function of adoption fraction, which is a fraction of the population that takes on the new technology after exposure to it, the population using new technology and overall population of a country. The specific relationship is presented by equation (2):

$$\mathrm{AR} = \left[(\mathrm{CR} * \mathrm{AF}) * \left(1 - \frac{\mathrm{PUNT}}{\mathrm{CP}} \right) \right] \tag{2}$$

where CR stands for Contact Rate, AF for Adoption Fraction, PUNT for Population Using New Technology and CP country for Population.

Equation (2) eludes to the fact the rate at which people will adopt new technology will dependent on how often those that have embraced new technology will come into contact with those that have not yet. In addition, it will dependent on the proportion of the population who having been exposed to the new technology will embrace it. The second part of the equation "(1- PUNT/CP)" captures the fact that rate of change will vary overtime depending on the ratio of people using new technology to the country population. At the extreme when PUNT = CP, in which case the rate of growth will be zero as all people will now have embraced new technologies.

It is assumed a country's total population is a sum of potential users of new technology and the people using technology hence equation (3):

$$\mathrm{PANT} + \mathrm{PUNT} = \mathrm{CP} \tag{3}$$

where PANT stands for Potential Adopters of New Technology

It follows therefore that people using new technology at any time will be a function of adoption of new technology and initial population using new technology at the reference period as presented in equation (4).

$$\mathrm{PUNT} = \sum(\mathrm{ANT}, \mathrm{IPUNT}) \tag{4}$$

where ANT stands for Adoption of New Technology and IPUNT for Initial Population Using New Technology.

From equation 1-4 the specific number of people using new technology at a specific time will be according to equation (5):

$$\begin{aligned}&\mathrm{Popn\_Using\_New\_Techn}(t-dt)+\\&(\mathrm{Adapting\_of\_New\_Techn}-\mathrm{Falling\_Back\_to\_Old\_Techn})\\&*\mathrm{dtINITPopn\_Using\_New\_Techn}\end{aligned} \tag{5}$$

Fig. 1 below presents the visual articulation of the technology adoption process explained above in form of a stocks and flows diagram. The diagram makes explicit the causal and feedback effects assumed in the model. It also makes it easy to internalise the logic behind the model.

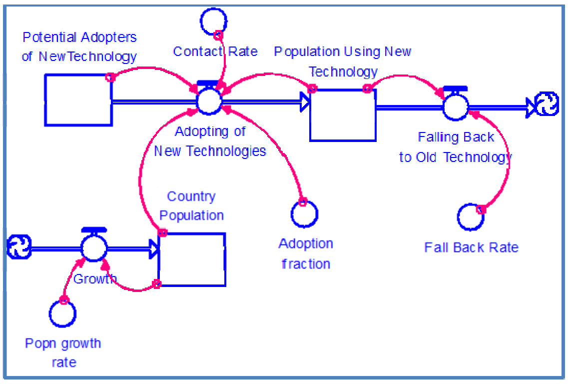

Fig. 1 stocks and flow diagram of technology adoption process

V. Simulation of Technology Diffusion Over Time

The above model was simulated for a hypothetical population of 10,000 people based on the assumption that increased diffusion will lead more adoption of the technology. In Fig. 2 the population that will adopt new technologies with population growth fraction set at 0.001, 0.025 and at 0.05 is presented. Model simulation shows the more stable the population of a country or society, the higher the threshold of that population that will adopt new technologies given a specific contact rate and adoption fraction.

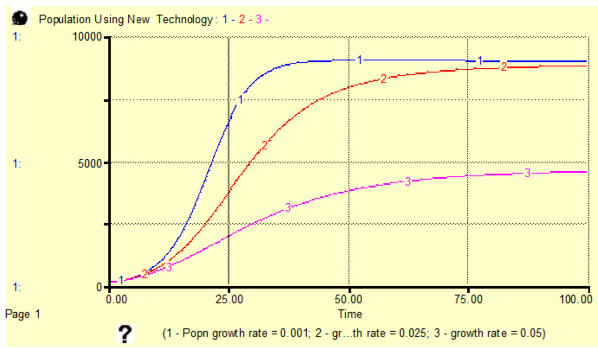

Fig. 2 Population using new technology with varying population growth rates

Effect of adoption fraction and contact rate on population's adoption of new technology overtime is comparable. Holding other factors constant, the lower the adoption rate, the longer it will take to reach the maximum number of technology users in a country or a particular society. Ultimately the same number of technology users is reached. Fig. 3 shows trend in the population using new technology with technology adoption set at 0.5, 0.35 and at 0.2.

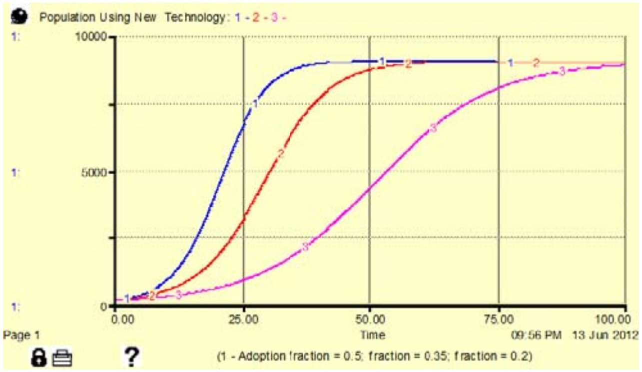

Fig. 3 Population using new technology with varying technology adoption fraction

Finally, the number of people using new technology is very sensitive to the fall back rate: Fig. 4 shows trend in the population using new technologies with technology fall back rate set at 0.0001, 0.001 and at 0.01. At relatively high rates of fall back, overall gains made in making people adopt new technology end up being reversed (Trend 3).

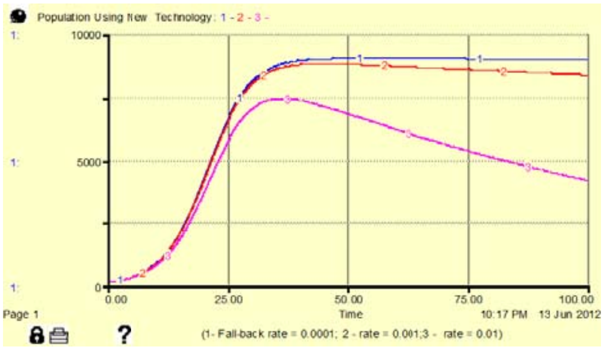

Fig. 4 Population using new technology with varying technology fall-back rate

VI. Insights and Recommendations

To the extent that technology diffusion has a bearing on economic growth and inclusive development, policy makers in African countries need to have some insight in what aspects may accelerate or hinder more people in adopting new production technologies. From the technology diffusion model above, they need to interrogate country specific factors that influence technology adoption and that accelerate contact between users and non-users of new technology. Moreover, they should pay special attention to identify factors that lead to technological relegation as captured by the fall back rate in the diffusion model.

It must be acknowledged that some of the factors that influence technology diffusion are not confined within the domain of economics or conventional technology studies. Nonetheless, they ought to be part of the wider effort to attain sustainable and inclusive development in Africa. More research in this area is therefore needed.

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