© Kamla-Raj 2015 J Hum Ecol, 51(1,2): 141-149 (2015)
PRINT: ISSN 0970-9274 ONLINE: ISSN 2456-6608 DOI: 10.31901/24566608.2015/52.1,2.15

Technology Diffusion and Economic Growth: An Alternative Conceptual Model

Tabukeli Musigi Ruhiiga

Department of Geography and Environmental Sciences, School of Environmental and Health Sciences, Faculty of Agriculture, Science and Technology, North West University, Private Bag X2046, Mmabatho 2735, South Africa

KEYWORDS Technological Change. Technical Efficiency. Growth Accounting. Labour Efficiency. Innovation

ABSTRACT Technological development goes beyond the acquisition of requisite skills through environmental exposure, education and training to the ability to engage in innovative tasks whose results include improved processes, systems, higher levels of performance, greater efficiency and new products. This article reports the results of a study centred on the links between technology diffusion and economic growth in order to present an alternative interpretation of their role. The methodology involved an initial review of growth accounting procedures, the use of secondary data on registration of patents, energy generation statistics, income per capita and GDP. Next, using internet search engines, technology transfer, adoption and innovation are unpacked in the context of contemporary models of innovation, diffusion and adoption. The resulting elements are reconfigured into linear information flows that mimic knowledge transfer between the phases of the system with specified outcomes. The findings indicate mixed outputs on the basis of which an alternative conceptual model is developed.

INTRODUCTION

Technology transfer, diffusion, adoption and innovation have attracted a significant volume of literature in the recent past (Been-Lon et al. 2002; Ghobakhloo et al. 2012; Tigabu et al. 2015; Assiotis et al. 2015; Perla et al. 2015) but a distinction between the determinants of transfer and those for adoption often create serious problems of interpretation. The forces that drive the transfer process, that is, the way a given technology is exported from centres of production to other places and adoption, which is the actual up-take of this technology by individuals, households, institutions, firms are not exactly the same. The general determinants of adoption are reported in Hall and Khan (2003) and in Postelnicu and Dabija (2015) while the diffusion process is often driven by economic forces around demand, supply, pricing, competition and market signalling (Ruhiiga 2011). In a technical context, innovation defines a new invention that often radically transforms industrial processes leading to a new barrage of products (Dinlersoz and Pereira 2007; Gruber and Verboven 2001). In general, there is a fair understanding of the forces that determine innovation, diffusion and adoption (Hall and Khan 2002; Dechezleprêtrea et al. 2015) but as will be seen, modelling of these processes immediately reveals loop-holes in the general state of knowledge with regard to the interface between technology and economic growth (Been-Lon et al. 2002). It is necessary to indicate that innovation, diffusion and adoption behavior of firms (Dibrell et al. 2008), households and institutions vary; meaning that the key measures for these three different individuals are not the same.

Even at the level of a single country, innovation, technology transfer and adoption show immediate variability for practically every new technology. Current explanatory approaches often do not distinguish between the different decision units and the fact that their response behavior cannot be captured by a single model. The production units (P's) of interest; individuals, households, groups, communities, institutions and firms display different behavioural characteristics in the face of a new innovation and the technologies it unleashes. Because the technology market is by nature segmented at various levels; income, location, ethnicity, age, gender, social classes and scale, what the over-

Address for correspondence:
Tabukeli Musigi Ruhiiga
Department of Geography and Environmental Sciences,
School of Environmental and Health Sciences,
Faculty of Agriculture, Science and Technology,
North West University,
Private Bag X2046,
Mmabatho 2735, South Africa
Telephone: (+27) 18 3892310
Fax: (+27) 18 389 2637
*E-mail:*Tabukeli.ruhiiga@nwu.ac.za

all market displays as response is basically an aggregation of minute differences in response. Using a spatial dimension approach, innovation originates at few centres of specialized knowledge production; its transfer-often occurring in waves- is affected by existing technology and a series of other drivers but its actual adoption by various P's is a product of demand, supply, market, policy forces in the context of the bio-physical environment. The processes of innovation, diffusion and adoption are well known; but what has remained controversial is the link between these processes and economic growth. That is, the variations in the rates of economic growth triggered by technology, display the effects of scale, location and intensity. Quantifying the impact of technology adoption on economic growth (Crafts 2003a) remains essentially problematic. Too much attention, needless to say, has tended to be put on the innovation-diffusion-adoption interface but little on how adoption, in particular, translate into economic growth. The existence of stark differences in the location of innovation means that diffusion and adoption cannot simply be explained away by sighting empirical evidence around market forces, relative location, information access, consumer preferences, education and household income patterns. No work so far, to my knowledge, has attempted to distinguish between P's, drivers and outcomes in a time-space-response- continuum and to generate an applicable configuration.

Objectives

Three objectives are specified. The first is to provide a brief outline of the determinants of adoption; second is to comment on state of literature on technology and economic growth while the third is to suggest an alternative arrangement of input elements into a model.

MATERIAL AND METHODS

The use of traditional growth accounting procedures after Solow (1957) to measure indirectly the rate of technological progress, in an economy is a common practice. A country's total output is decomposed into an increase in the amount of factors employed, that is capital and labour and that portion which cannot be accounted for by factor inputs. This unexplained variance in the GDP is then taken to represent increases in productivity driven by technological advances. A country's total output is modelled as a production function:

$$Y=F(A,K,L) \qquad (1)$$

Where Y is total output; K is the stock of capital, L is labour or sometimes switched to stand for population, and A is the technology factor. It is possible to expand the production function to include resources (land and natural) as in (2)

$$Y=F(A,K,L,R) \qquad (2)$$

The assumption of constant returns to scale allows for perfect competition meaning that factors get their marginal products:

$$dY/dK=MPK=r \qquad (3)$$

$$dY/dL=MPL=w \qquad (4)$$

where MPK and MPL represent additional output produced by capital and labour respectively. Wages paid are denoted by *w* while the rate of interest is shown as *r*.

A total differentiation of the production function gives:

$$dY=F_A dA+F_K dK=F_L dL \qquad (5)$$

where F_i denotes the partial derivative in terms of factor i, or for the case of labour and capital, marginal products. Assuming perfect competition the equation becomes:

$$dY=F_A dA=MPKdk+MPLdL=F_A dA+rdK+wdL(6)$$

dividing through *Y* and converting each change into growth rates produces:

$$dY/Y=(F_A A/Y)(dA/A)+(rK/Y)^*(dK/K)+(wL/Y)^*(dL/L) \qquad (7)$$

denoting a growth rate in terms of % change over time of a factor as $g_i=di/_i$, we get:

$$gY=(F_A A/Y)^* g_A+(rK/Y)^* g_K+(wL/Y)^* g_L \qquad (8)$$

where rK/Y is that part of total income that goes to capital, denoted as α and, wL/Y is that share that goes to labour, shown as 1-α. Equation (8) now becomes:

$$gY=F_A A/Y^* g_A+\alpha^* g_K+(1-\alpha)^* g_L \qquad (9)$$

The problem is that the terms *gL, gK,* α*, and gY* can be observable and measured using national income statistics. The term $F_A A/Y^* g_A$ cannot be directly observable as it defines improvements in productivity not related to changes in the use of factors. This is often called the Solow Residual or total factor productivity growth (TFP) meant to represent the contribution of technological progress in a country's growth. It is possible to re-arrange equation (9) in order to measure this quantity as that part of increase in total output not due to the weighted growth of factors:

Solow residual=$g_Y-\alpha^* g_K-(1-\alpha)^* g_L$ *(10)*

Growth accounting procedures are criticized (Greenwood and Krusell 2007) for questionable interpretation and instead believe that quantitative theory is a better medium. Additional criticism centre on its base assumptions, that only labour, capital and technology are responsible for economic growth; the failure to model the role of government policy, the failure to factor in variations in the level of technology across a single state and, the assumption that the unexplained variance captures technology while it may in reality be an umbrella term for all those drivers not covered in the standard growth model after Solow. In this study, information on technology diffusion is accessed from internet sources of current journals reporting research in recent years. This is followed by statistics reporting the global status of patents in force (WIPO 2014); electricity generation, GDP and per capita GDP for the leading top 30 nations. Finally, a brief survey of assumptions and premises of contemporary models in organizational behavior and in economics is presented.

RESULTS AND DISCUSSION

Determinants of Technology Diffusion

Results are reported in the context of objectives, earlier specified in section 1. The determinants of adoption are well documented (WPO 2010; Gandal et al. 2000; Milliou and Petrakis 2009) but the variations in these arise depending on which unit of production (*P*) is the point of departure. In terms of innovation, a non- inclusive list would mention state policy on technology, business investment, state of university education, taxation regime, regulation of patent registration, competitiveness of the economy, income per capita and GDP, size of domestic market, level of industrialisation, international trade participation, location, existing technology and information access. For diffusion, Caselli and Coleman (2001) reporting their findings on computer adoption, indicate that high levels of correlation with human capital and manufacturing openness; high investment rates, good property rights and protection and, a small share of agriculture in a country's GDP. Adoption of technology is reduced by a large share of government in GDP but increased by a large share of manufacturing. Geroski (2000) investigates what gives rise to the S-curve in diffusion patterns. The findings of this work indicates the variable impact of technology policy on technology diffusion and, the critical role timing the introduction a new technology plays. As for adoption (Migiro and Ochola 2005) cite several factors: availability; social space/environment; acceptability of the new technology; geographical barriers; benefits of new technology; political barriers; affordability; income per capita; compatibility with existing technology; type of technology; cost of technology to the final consumer; cost of switching from an existing technology to a new one and support infrastructure and services. It will be noted that adoption itself is pre-processed through innovation and diffusion waves leading to the inevitable proliferation of response possibilities in time and location.

State of Literature

Information on the state of literature with reference to technology and economic growth remains diverse. Modelling the impact of technology on economic growth has usually taken the form of an augmented Solow model by Mankiw et al. (1992) where human capital is critical for long term growth and where either the assumption of identical technology or that of treating technology differences as residuals in the growth equation is followed. Hall (2011) has shown a high correlation between productivity levels and output per worker but according to Boulhol (2004) the cross section literature does not show evidence that the implications have been vigorously pursued. Indeed, the link between productivity and diffusion is not obvious. If the higher outputs per work are cited as evidence of the application of technology, this would still not indicate how it is related to the technology diffusion process. In the meantime, in line with recent models sparked by the Solow Paradox, the initial impact of GPT (electricity, steam and ICT) may be negligible or even negative (Crafts 2003b). The impact of technology on economic growth remain mixed partly because of problems of establishing the level of technology at the nation state and isolating that part of economic growth driven purely by labour efficiency. The way institutions impact on technology differences through efficiency in technology use, long term TFP growth and technology diffusion remains poorly understood. Attempts at imposing the Cobb-Douglas production function on tracing the impact of technology are beset by limitations. First, the function has an inbuilt mathematical error in that it assumes that the Cobb-Douglas applies at both the micro-scale and macro-levels. In the same vein, it may not be necessarily true that the function is applicable at the disaggregated level. Secondly, the Cobb-Douglas function was not originally based on an existing theoretical knowledge platform in either engineering, management or technology. It therefore has no micro-foundations that one can talk of. In spite of these drawbacks, both growth accounting and the use of regression provide consistent results (Bosworths and Collins 2003).

Specific modelling effort highlights critical limitations in understanding the interface between technology and economic growth. But these models should be evaluated on the basis of what they are meant to address rather than assuming that all target addressing a similar problem. In terms of diffusion models, four models are commonly cited in the literature with respect to both diffusion and adoption. First, the *epidemic model* is based on the premise that what limits the speed of usage of a given technology is the lack of information about it, how to use it and what it does (Geroski 2000). Second, the *probit-model* is based on the premise that different firms with different goals and capabilities are likely to want to adopt a technology at different times. Here, adoption becomes a result of strategic timing (Aghion et al. 2005; Blundell et al. 1999). Third, the *density dependency model*, popularized by ecologists is built on the premise that of the twin forces of legitimization and competition. These push the establishment of new technologies but eventually limit their uptake. Fourth, *information cascade models* refer to where the initial choice between variants of a new technology affect the consequent diffusion speed. Once a particular variant has become finally established- following the elimination of competitors, the result is a herd like consumption spread. Pavlova (2001), for example uses capital-based costs, to derive a formula for growth accounting and discuss the effects of the model's parameters on the pace of technology adoptions and sizes of technology upgrades concluding that uncertainty adversely affects growth and firm value. Different approaches in technology adoption specific to sectors are reported (Thong 1999; Pan and Jang 2008; Nguyen 2009; MacGregor and Vrazalic 2005).What is true of all these models is the emphasis on processes inherent in the innovation-diffusion-adoption chain with limited progression into confronting the drivers of economic growth.

The state of patents across the leading countries on a global scale (WIPO 2008) show that the dominance of the northern hemisphere is unquestioned. But the combined regional status of China, South Korea, Hong Kong and Japan (WIPO 2014) as a node for the knowledge economy cannot be ignored. The critical measure here is patents in force which indicate a dominance of the leading industrialised nations. But the structure of patent applications indicates variability across these countries and beyond. According to WIPO (2010) business applicants accounted for the majority except in Russia, Brazil and South Africa where individual applicants accounted for the largest shares. Overall, the business sector's investment in appears to be the main driver for technology development. Ireland (21.6%), Spain (14.7%) and Singapore (13.2%) had the highest shares from the university sector. Government and research institutions were most prominent in Singapore (26.9%), South Korea (9.9%) and in France (8.9%).

Centres of innovation indicate a dominance of innovation, diffusion and adoption in the northern hemisphere and limited trickle down effects into New Zealand, Australia, Brazil, South Africa and Mexico. These countries happen to have a long established tradition of European settlement, colonisation and post-independence trade linkages, apart from Mexico, such that their domestic markets make them an extension of western Europe. The history of diffusion of technology shows that in the last 100 years, the rates of consumption of new technologies linked to the use of electricity, motor vehicles and refrigeration appear to be faster than in the past. In a comparison of the leading 20 countries in terms of electricity consumption per capita-(kwh per person), and GDP (purchasing power parity) in US billion $(CIA 2012), indicate a close correlation. This seems to support the view that electricity generation could be used to trace the levels of technology across countries. Note that the score for GDP per capita indicates that the USA falls to position 11 indicating that per capita income alone may not be a consistent criteria in measuring a country's wealth status.

A global technology index (GTI) has been suggested based on research and development effort, scientific and research talent, and the level of innovation (Florida 2011). The GTI generates outcomes not exactly similar to conclusions about the state of inter-country comparisons in the level of technology. Israel, Sweden, Finland, Japan and Switzerland lead. In scientific and research talent, Finland leads followed by Sweden, Japan, Singapore and Denmark. In terms of innovation measured as patents per capital sees USA, Japan, Switzerland and Israel as the leading nations. When these are combined, Finland, Japan, USA and Israel score the highest GTI. The use of indices as a measure of comparative performance is beset with internal problems of design and interpretation.

The limitations of modelling the technology-economic growth relationship are acknowledged (Raia and Robinson 2015) and the reconfiguration of input factors is not meant to discard growth accounting procedures currently in widespread use. Instead, it is meant to provide an alternative vehicle that may throw light on the link between technology and economic growth. What is suggested here is therefore, a conceptual model that is sensitive to criticisms that growth accounting attracts. The initial point of departure is the interface between adoption and growth. The re-configuration of inputs into the economic growth equation is built around the identification of production units - hereafter shortened to *P.* These *P*'s include *individuals (1), households (2), groups (3), communities (4), firms (5) and institutions (6).* Every form of production can be housed within the *P1…..P6* classes and the following assumptions apply.

- The the identity of *P* in terms of the adoption of a particular technology has a significant time-space- control over the response possibilities.
- The the ability to deploy on a large scale a new technology into production activities is at the core of economic growth. The deployment of technology into production requires significant initial investment in capital.
- The state of existing technology and its support platform of services and infrastructure has a significant attraction or retardation effect on future technology-growth multipliers in the national economy.
- The accumulated technical capacity of a country (technology index-GTI) which is the ability to adapt technologies into various production options will facilitate greater and faster deployment of new technologies if and when adequate synergies already exist for lateral and vertical integration of other inputs. On the basis of these four premises, the interactions between the various *P*'s and attributes is represented in Table 1.

Where Inn= innovation, Diff=diffusion, ado=adoption, *Δ*= delta, *l*=location, t= existing technology, i= information access, y=type of technology, k=cost of technology to the final consumer, d= decision-making process, b=benefits of adopting the new technology, s=cost of switching from an existing technology to a new one, *= support infrastructure and services. The adoption interface is presented in the context of $P_1…..P_6$ and drivers, (x) denoted as-time, cost, type, information access, policy, technology use, markets, social space, benefits, support infrastructure and services, decision-making, location across $X_1…..X_n$ respectively. The rate at which technology is adopted and deployed into the production process which in turn generates growth multipliers varies depending on the identity of the players within a social space that imposes its own controls (facilitates or militates) the onward wave of adoption in time-space.

The time-space-response continuum is a natural development from the representation of variable interactions involved technology adoption. It captures the essence of imbedded variations in the possibilities of response by various *P*'s. In Table 2, the differences in scale, identity,

Table 1: Technology context

Players	*Inn*	*Diff*	*Ado*	*Players*	*Inn*	*Diff*	*Ado*
P_1 -Individuals	*Älti*	*Äyik*	*Ädbs**	P_4 -Communities	*Älti*	*Äyik*	*Ädbs**
P_2 -Households	*Älti*	*Äyik*	*Ädbs**	P_5 -Firms	*Älti*	*Äyik*	*Ädbs**
P_3 -Groups	*Älti*	*Äyik*	*Ädbs**	P_6 -Institutions	*Älti*	*Äyik*	*Ädbs**

Source: Author

existing technology platform, ETP, change in technical capacity TC, government and market accounts for variations both in the intensity of economic growth across the national economic space and more importantly, differences in the actual contribution to such growth accounted for by technology.

Where Δ= change in scale and identity; ?=unpredictable; *Δ* ETP=change in existing technology; *Δ* TC=change in technical capacity; ↔= variability in state policies on technology, investment and markets; ↕= market behavior, especially response to new technological products and services. The relationships are combined into a flow-line conceptual model in Figure 1. The configuration is built around production units, technology platform, government and market.

The arrows represent feedback in the form of information processing layers of decision making. At level one, decision making units at the apex of centres of production (*P*'s) and combinations thereof become aware of a new technology. The way these units of production respond to a new technology varies in time, space and intensity producing a spectrum of possibilities. The idea of a possibilities frontier captures this diversity indicating that some of the responses do not link up with the next level. These represent barriers to adoption as reported in Parente and Prescott (1994) and in Madrid-Guijarro et al. (2009). Those *P*'s that adopt the technology represent the actual uptake of this new innovation and this feeds into the existing technology platform at level 2. The technology platform describes the totality of the present level of technological development in a country. It includes patents in force, level of expenditure, size of scientific and research community and, the ranking of the country in terms of electricity genera-

Table 2: Technology and economic growth

Scale	*Identity*	*Ä ETP*		*Ä TC*	*Ä Government*	*Ä Market*
Locality	Ä	?		?	↔	↕
District	Ä	?	↕	?	↔	
Provincial	Ä	?		?	↔	
Regional	Ä	?		?	↔	
National	Ä	?		?	↔	

Source: Author

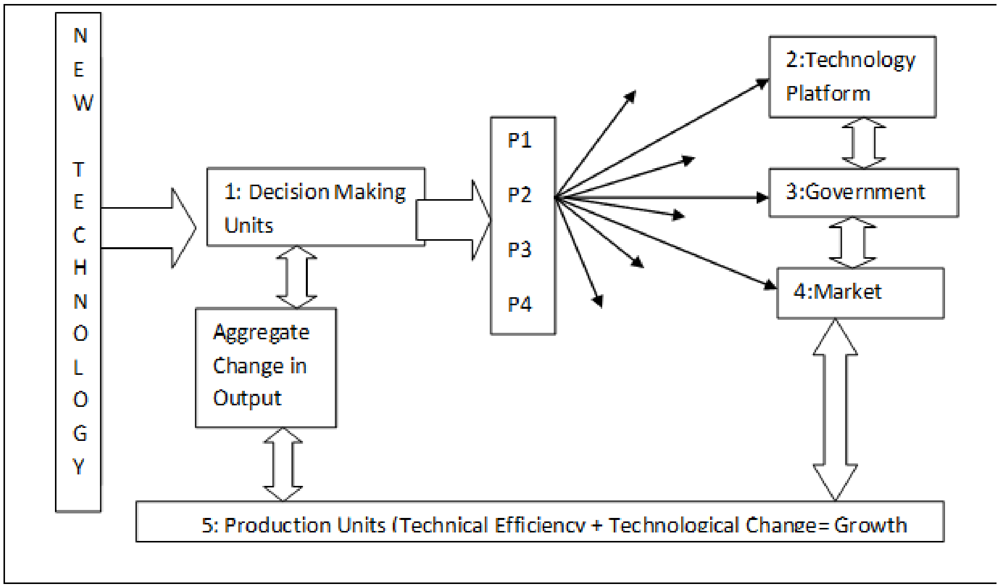

Fig. 1. A time-space-continuum model

tion. Level 2 predetermines the possibilities for support from level 3- government.

Level 3 is responsible for economic policy, investment policy, institutions, the legislative environment, economic structure and the extent to which government pursues and supports an industrial growth policy. Information generated at level three is then transferred to level 4, the market space. Here, access to services, the state of infrastructure, barriers to investments, size of domestic market, mean income per capita across the country, access to international markets, costs of investments, fiscal stability, resilience of the domestic economy in the face of global market shocks, risk perception, labour efficiency, access to capital and finance and ultimately, the competitiveness of the country's economic landscape play a critical role. The market space generates information that captures current trends and points to future growth directions. In short, it generates signals which have to be processed at level 5 where production units integrate technological changes directly tied to the new technology and, technical efficiency arising out of slower adjustment behavior of firms and other production units. The outputs of level 5 are fed into level 1 via an organisational learning process in the form of greater aggregate outputs. A second cycle is thereby initiated setting into motion a continually changing production landscape in time and space. Note that while the re-configuration of these processes appear as an orderly phase-by-phase-network, in reality this is a complex interplay of signals-response-change imposed on a moving platform.

Where the configuration in Figure 1 is novel is in the sense in which it bridges the gap between adoption and deployment into the economic growth process and provides an explanation for inherent spatial gaps in the levels of technology at the country scale. Most conceptual models are sector specific and built around an organisational behaviour platform concerned more with internal processes of diffusion and its transfer into adoption and implementation thereof (Nguyen 2009; Al-Gahtani and King 1999; Wixom and Todd 2005; Jones et al. 2005; Macgregor and Vrazalic 2005; Ghobakhloo et al. 2010). The ultimate focus of these models is not in tracking the effects of technology on economic growth. Underlying the premise of the thrust is that maximizing the number of participants across *P*'s who adopt a given technology increases the probability of greater investments using this same technology (Gilligan 2012). For economic growth to occur, there has to be an expanded level of investment in time-space translating into greater volumes of production and a direct impact on income levels. This calls for the ability to see in the adopted technology, possibilities for enhancing production through greater labour efficiency, savings that arise in lower costs of production and greater economies of scale. The interaction between the *P*'s and 2-3-4 creates a variable social space which may facilitate or retard possibilities for technology diffusion. The links between 2-3-4 imply the existence of synergies in the transmission of appropriate information conducive to increased uptake of new technology. Once again, a possibilities frontier operates parallel to these links. The layers of information processing and decision making from level 1 through 5 back to 1 in the context of uncertainty at different scales generate a wide spectrum of production responses.

A distinction is made between technological change (TC) arising out of the widespread adoption of a new technology by production units and technical efficiency (TEC) reported in Karanja et al. (2012) which is the response of those production units that market signals compel them to adapt to the threat of this new technology by improving performance. The gist of this article has been centred on the TC component and the resulting conceptual model does not include the impact of TEC on overall economic growth. Needless to say, both TC and TEC do have an accumulative effect on total output but reporting on the outcomes between adopters and non-adopters in the context of economic growth performance falls outside the thrust of this article. Citing empirical support for the ideas expressed in this model calls for another paper as space does not allow this to be done in the current paper.

CONCLUSION

The findings of this study have highlighted the less than satisfactory state of knowledge on the understanding of the link between technology diffusion and economic growth. This remains an area of research interest and debate. The conceptual model developed in this paper, remains, exploratory. More rigorous work is needed to convert the inputs into growth variables and to test the assumptions with real economic performance data. In the meantime, the use of a time-space-response-continuum indicates a possibilities frontier that may underpin the persistence of inequality in the spatial character of the economic growth process.

RECOMMENDATIONS

On the basis of the findings, three recommendations are advanced. First, further research is still needed in understanding the drivers of economic growth as a point of departure for apportioning the contribution of technology in the overall economic growth process. Second, research effort in linking the barriers to diffusion in the context of a continually shifting time-space-platform is necessary because this area of study is poorly represented in contemporary literature. Third, investigating the elements that lead to a receptive environment for technology diffusion beyond the behaviour of industrial firms may generate new insights.

ACKNOWLEDGEMENT

North West University, Mafikeng Ccmpus is herby achnowledged for its financial support for this study.

REFERENCES

Aghion P, Bloom N, Blundell R, Griffith R, Howitt P 2005. Competition and innovation: An inverted-U relationship. *The Quarterly Journal of Economics*, 120: 701-728.

Al-Gahtani SS, King A 1999 Attitudes, satisfaction and usage: Factors contributing to each in the acceptance of information technology. *Behaviour and Information Technology,* 18(4): 277-297.

Assiotis A, Zachariadis M, Savvides A 2015. What Determines Technology Diffusion Across Frontiers? R&D Content,Human Capital and Institutions. *Economics Bulletin*, 35(2): 856-870.

Been-Lon C, Mo JP, Ping W 2002. Market frictions, technology adoption and economic growth. *Journal of Economic Dynamics and Control*, 26(11): 1927-1954.

Bosworth B, Collins SM 2003. *The Empirics of Growth: An Update.* USA: Brookings Institute and Georgetown University.

Blundell R, Griffith R, Van Reenen J 1999. Market share, market value and innovation in a panel of British manufacturing firms. *Review of Economic Studies*, 66: 529-554.

Boulhol H 2004. *Technology Differences, Institutions and Economic Growth: A Conditional Conditional Convergence*. No. 2004-02, CEPII, Paris.

Caselli F, Wilbur WJC 2001. Cross-country technology diffusion: The case of computers. *American Economic Review,* 91(2): 328-335.

CIA 2012 The World Fact Book. From <https://www.cia.gov/index.html.> (Retrieved on 12 May 2015).

Crafts N 2003a. Quantifying the Contribution of Technological Change to Economic Growth in Different Eras: A Review of the Evidence. *Working Paper* No. 79/03. London: London School of Economics and Political Science.

Crafts N 2003b. Steam as a general purpose technology: A growth accounting perspective. *Economic History Working Articles* 22354. London: London School of Economics and Political Science.

Crafts N 2010. The contribution of new technology to economic growth: Lessons from economic history. *Revista de Historia Económica*, 28(3): 409-440

Dibrell C, Davis PS, Craig J 2008. Fuelling innovation through information technology in SME's. *Journal of Small Business Management*, 46: 203–218.

Dinlersoz E, Pereira P 2007. On the diffusion of electronic commerce. *International Journal of Industrial Organization,* 25: 541-574.

Florida R 2011. The World Leading Nations for Innovation and Technology. From <http://www. CityLab. com/tech>.

Gandal N, Kende M, Rafael R 2000. The dynamics of technological adoption in hardware/software systems: The case of compact disc players *Rand Journal of Economics,* 31: 43-61.

Geroski PA 2000. Models of technology diffusion. *Research Policy*, 29(4/5): 603–625.

Ghobakhloo M, Zulkifli NB, Aziz FA 2010. The interactive model of user information technology acceptance and satisfaction in small and medium-sized enterprises. *European Journal of Economic, Finance and Administrative Sciences*, 19: 7-27.

Ghobakhloo M, Hong TS, Sabouri MS, Zulkifli N 2012. Strategies for successful information technology adoption in small and medium-sized enterprises. *Information*, 3(1): 36-67.

Gilligan DO 2012. Biofortification, agricultural technology adoption, and nutrition policy: Some lessons and emerging challenges. *CESifo Economic Studies*, 58(2): 405-421.

Greenwood J, Krusell P 2007. Growth accounting with investment-specific technological progress: A discussion of two approaches. *Journal of Monetary Economics,* 54: 1300–1310.

Gruber H, Verboven F 2001. The diffusion of mobile telecommunications services in the European Union. *European Economic Review*, 45: 577-588.

Hall BH, Khan B 2003. Adoption of Technology. *Working Paper* No.E03330. Department of Economics, University of California, Berkeley, CA.

Hall BH 2011. Innovation and Productivity. *Article prepared for the Nordic Economic Policy Conference on Productivity and Competitiveness*, 29 April 2011, Helsinki, Finland.

Jones RA, Jimmieson NL, Griffiths A 2005. The impact of organizational culture and reshaping capabilities on change implementation success: The mediating role of readiness for change. *Journal of Management Studies*, 42: 361-386.

Karanja F, Gilmour D, Fraser I 2012. Dairy Productivity Growth, Efficiency Change and Technological Progress in Victoria. Research Article 2012.5. *Paper presented at the Annual Conference of the Australian Agricultural and Resource Economics Society*, 7-10 February, Fremantle, Western Australia.

MacGregor RC, Vrazalic L 2005. A basic model of electronic commerce adoption barriers: A study of regional small businesses in Sweden and Australia. *Journal of Small Business and Entrepreneurship Development,* 12: 510–527.

Madrid-Guijarro A, Garcia D, VanAuken H 2009. Barriers to innovation among Spanish manufacturing SMEs. *Journal of Small Business Management*, 47: 465- 488.

Mankiw NW, Romer P, Weil DN 1992. A contribution to the empirics of economic growth. *The Quarterly Journal of Economics*, 107(2): 407-437.

Migiro SO, Ocholla DN 2005. Information and communication technologies in small and medium scale tourism enterprises in Durban, South Africa. *Information Development*, 21: 283–294.

Milliou C, Petrakis E 2009. Timing of Technology Adoption and Product Market Competition. CESIFO Working Article No. 2686, Category 11: Industrial Organisation. June 2009. *Presented at CESifo Area Conference on Applied Microeconomics*, March 2009.

Nguyen TUH 2009. Information technology adoption in SME's: An integrated framework. *International Journal of Entrepreneurship Behaviour and Research*, 15: 162-186.

Pan M, Jang W 2008. Determinants of the adoption of enterprise resource planning within the technology-organization-environment framework: Taiwan's communications. *Journal of Computer Information Systems*, 48: 94-102.

Parente SL, Prescott EC 1994. Barriers to technology adoption. *The Journal of Political Economy*, 102(2): 298-321.

Pavlova RR 2001. Small economies and the challenge of globalisation. *Economic Thought Journal,* 1: 86-103.

Perla J, Tonetti C,Waugh, E 2015. Equilibrium Technology Diffusion, Trade, and Growth. *NBER Working Paper No. 20881.*

Postelnicu C, Dabija DC. 2015. Transfer and Diffusion of New Technologies Within the Supply Chain of Multinational Companies with Operations in Romania—A Contemporary Approach. *Springer Briefs in Political Science*, pp. 53-66.

Raia V, Robinson SA 2015. Agent-based modeling of energy technology adoption: Empirical integration of social, behavioral, economic, and environmental factors. *Environmental Modelling and Software,* 70: 163-177

Ruhiiga TM 2011. Settlement, location and rural production in sub-Saharan Africa: An alternative configuration. *Life Sciences Journal*, 8(SI): 140-146.

Solow R 1957. Technical changes and the aggregate production function. *Review of Economics and Statistics*, 39(3): 312-320.

Thong JYL 1999. An integrated model of information systems adoption in small businesses. *Journal of Management Information Systems,*15: 187-214.

Tigabu, AD, Berkhout F, Van Beukering P 2015. The diffusion of a renewable energy technology and innovation system functioning: Comparing bio-digestion in Kenya and Rwanda. *Technological Forecasting and Social Change,* 90: 331–345.

WIPO, 2010. *World Intellectual Property Organisation Statistical Database, 2010.* Geneva, WIPO.

WIPO 2014. *World Intellectual Property Organisation Statistics Database, October 2014.* Geneva, WIPO.

Wixom BH, Todd PA 2005. A theoretical integration of user satisfaction and technology acceptance. *Information Systems Research*, 16(1): 85-102.