TECHNOLOGY ROADMAPPING AND ROADMAPS IN A CONTEXT OF DEVELOPING COUNTRIES: A CONCEPTUAL FRAMEWORK

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ABSTRACT

The current technology roadmapping theory is typically based on third generation innovation models of the 1970s that couple linear models of technology push and market pull. There are incremental improvements to this field although the original philosophy on technology roadmapping and technology roadmaps is still prevailing. Unfortunately, the current technology roadmapping framework doesn't address sixth generation innovation models where there are complex interactions at a systemic level. This paper presents a conceptual framework for the technology roadmapping process and technology roadmap development for developing countries. The framework addresses the gaps in technology roadmapping and technology roadmap theory for technology catch-up strategies. It is derived from the literature on technology roadmaps' format and purpose; technology roadmapping processes; transition management and complex systems theory.

The framework proposes the need for transition orientated technology roadmaps in case of developing countries and technology catch-up strategies. These types of roadmaps initially focus on nurturing several niche innovations, with emerging technologies as the major form of technology areas. Through technology roadmap review and updates, the promising niche innovations are selected for upscaling.

The paper seeks to encourage wider adoption of technology roadmaps as a technology planning tool by firms and governments in developing countries. The literature on other technology planning and analysis tools such as technology foresighting have started to focus on customised frameworks for developing countries, although this gap has not been addressed from a technology roadmapping perspective. Further work is planned in future for testing and validation of this proposed framework.

Key words: technology roadmap, framework, developing countries, transition management, complex systems

INTRODUCTION

The technology roadmapping process was introduced in the late 1970s by former Motorola chairman, Robert Galvin (Gerdsri and Kocaoglu 2007). Since the introduction of this technology analysis and planning tool, there has been a considerable interest in theory and practice on its usage; its development process; customisation according to various management needs; integration with the organisations' strategic and operational processes; and integration with other technology planning tools. During the period 1970s to 1980s, at the time of technology roadmapping introduction, the dominant innovation model was the 3rd generation coupling model that is characterised by being a combination of market pull and research and development (R&D) push linear models (Hobday 2005). According to the author, this innovation model is based on central planning within an organisation with R&D and marketing more in balance through an emphasis on integration at the R&D – marketing interface. The model involves feedback loops from early to later stages of the innovation value chain. The characteristics of this 3rd generation innovation model resonate well with those of technology roadmaps.

Innovation models have since evolved to reflect innovation as a complex sociotechnical process, especially in a context of rapid globalisation. The 4th generation innovation model of between 1980s and 1990s was inspired by observation of Japanese corporations where innovation is not viewed as a linear or sequential process, but being perceived as composed of parallel processes (Rothwell 1992). These parallel processes are mentioned within (Hobday 2005) as strong upstream supplier linkages and partnerships; close coupling with leading edge customers; emphasis on integration between R&D and manufacturing; and horizontal collaboration including joint ventures and strategic partnerships. The 5th generation innovation model of post 1990 further strengthens a concept of parallel processes while also introducing information technology as a key decision support tool for R&D, technology development, product development and marketing. The move from integrated to networked innovation actors on this innovation model led to a concept of 'systems of innovation' (Chaminade and Roberts 2002). According to the authors, the 6th generation innovation model introduces knowledge capital (in place of information technology) of which more innovative firms "are able to create, maintain and use their knowledge resources in the most effective manner, allowing the firm to learn collectively".

This paper attempts to harmonise technology roadmapping theory with the recent developments on innovation models through the development of a technology roadmapping framework for complex innovation systems. An emphasis is placed on developing countries to assist managers, experts and policymakers in developing countries to adapt technology roadmapping processes to their environment. The paper is organised in four sections, the first being a literature review that attempts to bring consensus on constructs from different theories. The research methodology section explains an approach that will be followed, whereas a conceptual framework is proposed in a section that comes after. The last section is conclusions.

LITERATURE REVIEW

This section is divided into five sub-sections starting with theory on technology roadmapping. We briefly review the technology roadmapping process and how technology roadmaps are customised. A section on innovation within the global value chain summarises a complexity brought about by

globalisation with reference to developing countries. Finally, transition management for complex innovation systems is discussed to define key concepts on long range planning for complex systems.

Technology roadmapping: content and process

Technology roadmaps are commonly used around the world as a technology-market planning tool, especially within the multiple stakeholder environments where the intended future needs to be clearly communicated to various role players such as the innovators, entrepreneurs, customers, suppliers and the government. There is a distinction between technology roadmap and technology roadmapping although they are often used interchangeably. Technology roadmapping is a technology planning process that helps to identify, select and develop technology alternatives to satisfy a set of product needs (Garcia and Bray 1997). The initial Motorola technology roadmapping process was prepared and kept current by a small committee of individuals from Motorola's technical experts who are selected for their acknowledged expertise (Willyard and Mcclees 1987). According to the authors, although the corporate office maintained, revised and expanded technology roadmaps taking note of the new intelligence on technology and products landscape, the roadmaps were the tools for individual business managers and product designers.

The practice of governance of the technology roadmapping processes through a permanent committee has been widely adopted, an example being the International Roadmapping Committee as well as regional and international technology working groups for example the International Technology Roadmap for Semiconductors (ITRS). The International Microsystems and Top-Down Nanosystems Roadmap (IIMTDNR) roadmapping process is governed by the Executive Roadmapping Committee with similar functions to that of the ITRS governing committee (Walsh 2004).

Several researchers and practitioners have developed guidelines for different technology roadmapping processes (Walsh 2004; Gerdsri and Kocaoglu 2007; Daim et al. 2013; Phaal, Farrukh and Probert 2013). The proposed 3rd generation technology roadmapping model by Tierney, Hermina and Walsh (2013) attempts to address an increasing complexity of innovation that is not well addressed by traditional technology roadmapping methodologies. These complexity parameters are summarised by the authors in terms of innovation being developed at multiple root technologies; having no established technology product platform; having different technology critical requirements beyond Moore's Law of transistor density performance criteria; having more constraints on issues such as healthcare, energy, environment, food, and water; having new drivers such as changing customers' expectations, fluid intellectual procedures and resource requirements; and adoption of new business models such as consortia due to financial and skills shortages.

A technology roadmap, according to Garcia and Bray (1997), is the document that is generated by the technology roadmapping process. A generic format is typically sequential layers of R&D, technology, products, and market on the vertical axis and the time scale on the horizontal axis. The benefits of technology roadmaps are visualisation of the relationships between market, products, technology and R&D efforts, but also for communication with internal and external stakeholders of the firm or the industry (Yoon, Phaal and Probert 2008; Phaal and Yoshida 2014). Technology roadmaps as communication tools partially address the 4th, 5th and 6th generation innovation models of integrated, networked and knowledge based innovation processes.

Motorola had technology roadmaps that address single emerging technology and also products technology roadmaps to visualise and communicate potential future technological trajectories

(Willyard and Mcclees 1987). The IIMTDNR is an example of an emerging technology roadmap with less focus on product market, but more about forecasting the development and commercialisation of emerging technologies whereas ITRS is a technology to product roadmap (Walsh 2004; Tierney, Hermina and Walsh 2013). Various scholars have customised technology roadmaps according to their purpose, e.g. dual technology roadmaps for open innovation (Geum et al. 2013) and services technology roadmaps (Cho and Lee 2011).

Innovation management within the global value chain

Developing countries are known to be the net importers of technology and high-technology products in terms of trade balance. A persistent and sticky challenge that is well known is low levels of productivity (Lingela, Buys and Shimozawa 2007) that go along with high production costs, lack of key skills and lack of access to capital (Bartelsman and Doms 2000). According to Bartelsman and Doms (2000), aggregate productivity at a firm level is influenced by the factors that can be controlled by a firm (innovation activity, input choices and outputs) but also by market interactions (type of competition and market shares).

Within the scope of technology roadmapping, we analyse these competitiveness challenges faced by developing countries through the use of a value chain framework and the literature relating to the upgrading of the value delivery system. Kaplinsky and Morris (2001) define value chain as “the full range of activities which are required to bring a product or a service from conception, through the different phases of production, delivery to consumers and disposal”.

In value chain literature, the global value chain analysis that studies power relationships and information asymmetry between lead firms and other firms such as those in developing countries (Trienekens 2011) partially explains the productivity challenges and cost drivers that hamper innovation in developing countries. An important issue of significance is a concept of value chain governance, which is based on the fact that few lead firms in global value chain set and/ or enforce the parameters under which others in the chain operate (Humphrey and Schmitz 2002). According to the authors, some value chain aspects that are controlled by these lead suppliers are market access, fast track of production capabilities acquisition, support for host country policy initiatives and technical assistance. Global value chain governance has co-evolutionary characteristics due to continuous adjustments and changes (Pietrobelli and Rabellotti 2011). Kaplinsky and Morris (2001) view value chains as “repositories for rent which result from possession of scarce competitive resources and creation of the barriers to their access”. These barriers create superficial scarcity which results with super returns for innovations of lead firms.

The economic rent is explained by Kaplinsky and Morris (2001) as arising from differential productivity of factors (including entrepreneurship) and barriers to entry (scarcity); as relational rents arising from purposeful activities taking place between groups of firms; and in terms of its various forms such as technological capabilities, organisational capabilities, skills and marketing capabilities. Royalties and licenses on patents, franchises, trademarks and industrial designs are all typical examples of economic rent. According to Humphrey and Schmitz (2002), an increasing number of developing country producers engage in contract manufacturing as brands play a key role in purchase decisions of the customers. Increasing contract manufacturing trends result from the fact that a success in technological innovation depends on consumer acceptance.

For firms in developing countries to overcome their challenges within the vicious cycle characterised by lack of entrepreneurship, lack of innovation, lack of productivity, lack of skills, etc., they need to upgrade their participation in global innovation value chains to establish a new sustainable equilibrium. Various scholars have investigated mechanisms for value chain upgrade in developing countries (Humphrey and Schmitz 2002; Kaplinsky et al. 2003; Gereffi and Sturgeon 2013). This value chain upgrading unfortunately is in a form of being compliant to the demanding technology, production and products standards of the lead suppliers, rather than on developing countries' firms being equal partners within the global value chain.

Transition management for complex innovation systems

The developing countries' innovation systems represent a complex environment. This follows from the characteristics of complex systems such as persistent complex problems that are deeply embedded in societal structures, uncertainty due to hardly reducible structural uncertainties they include, difficult to manage due to diverse stakeholders with different interests and hard to control in the sense that they are difficult to interpret and ill structured (Rotmans and Loorbach 2009). According to Shiell, Hawe and Gold (2008), a complex system is adaptive to changes in its local environment, it is composed of other complex sub-systems and it behaves in non-linear fashion such that a change in the outcome is not proportional to a change in input.

Some characteristics of complex systems are emergent properties that are observed at the system level, but not at its individual parts (Choi, Dooley and Rungtusanatham 2001); and have adaptive and dynamic behaviour that maintains a stable equilibrium state through resistance and resilience (Limburg et al. 2002). Lucas (2000) described some complex system characteristics which were later grouped by Bertelsen (Bertelsen 2003) as composed of autonomous parts with certain behaviours (non-standard, co-evolutionary, self-modification, downward causation and self-reproduction) and in terms of non-linearity (emergence, multiple alternative attractors, phase changes and unpredictability).

Transition of complex systems takes place at multilevel which includes niche innovations, sociotechnical regimes and sociotechnical landscapes; hence successful transitions are a result of interactions among these three levels (Geels and Schot 2007). Transition based strategies and policies are aimed at stepping away from incremental developments along 'business-as-usual' trajectories (Vob, Smith and Grin 2009) by inducing and guiding complex processes of sociotechnical change by means of deliberation, probing and learning.

As transition management involves changes on sociotechnical systems from an established paradigm to the new one, innovation management in this context needs to be based on both technological innovation as well as social innovation. Social innovation according to Guaipatin and Humphreys (2014) is defined as "new solutions to challenges faced by people whose needs the market does not meet, and that have a positive impact on society. They must be carried out through an inclusive process, incorporating the beneficiaries (people) to adequately define the problem, and employing public–private–people partnerships towards the development of the solution".

Transition and complex system theories' concepts have been applied indirectly to technology roadmapping literature by several scholars such as Phaal, Farrukh and Probert (2004); Vojak and Chambers (2004); and Tierney, Hermina and Walsh (2013). The innovation process is getting more complex as per the 6th generation innovation model, hence these theories are useful for both

developing and developed countries. While developing countries' interests are in nurturing the niche innovations for upscaling, the firms in developed countries would like to prepare themselves for a potential of technology transitions in forms such as disruptive technologies.

RESEARCH METHODOLOGY

The technology roadmapping framework for developing countries is developed with a generic technology roadmapping process as a starting point. This approach was followed by various scholars in customising the technology roadmapping process (Han et al. 2012). Even though Walsh (2004) recognised that a traditional technology roadmapping approach is not suitable for disruptive technology roadmapping processes, a key observation is the fact that there is nothing wrong with the utilisation of technology roadmapping techniques, but rather with a blind application of these techniques in cases such as disruptive technology base. To address this concern, the literature such as that of complex systems and transition management is taken into account to reflect developing countries' innovation environment.

The roadmapping process as shown in figure 1 is composed of three phases, the first one being that of preliminary activities. It is during this first phase in which the strategic objectives are explicitly stated, and relevant stakeholders are identified and technology roadmapping governance is set up (Garcia and Bray 1997). The second phase is an actual development of the technology roadmap and the last phase is about follow-up activities that also include its review and update.

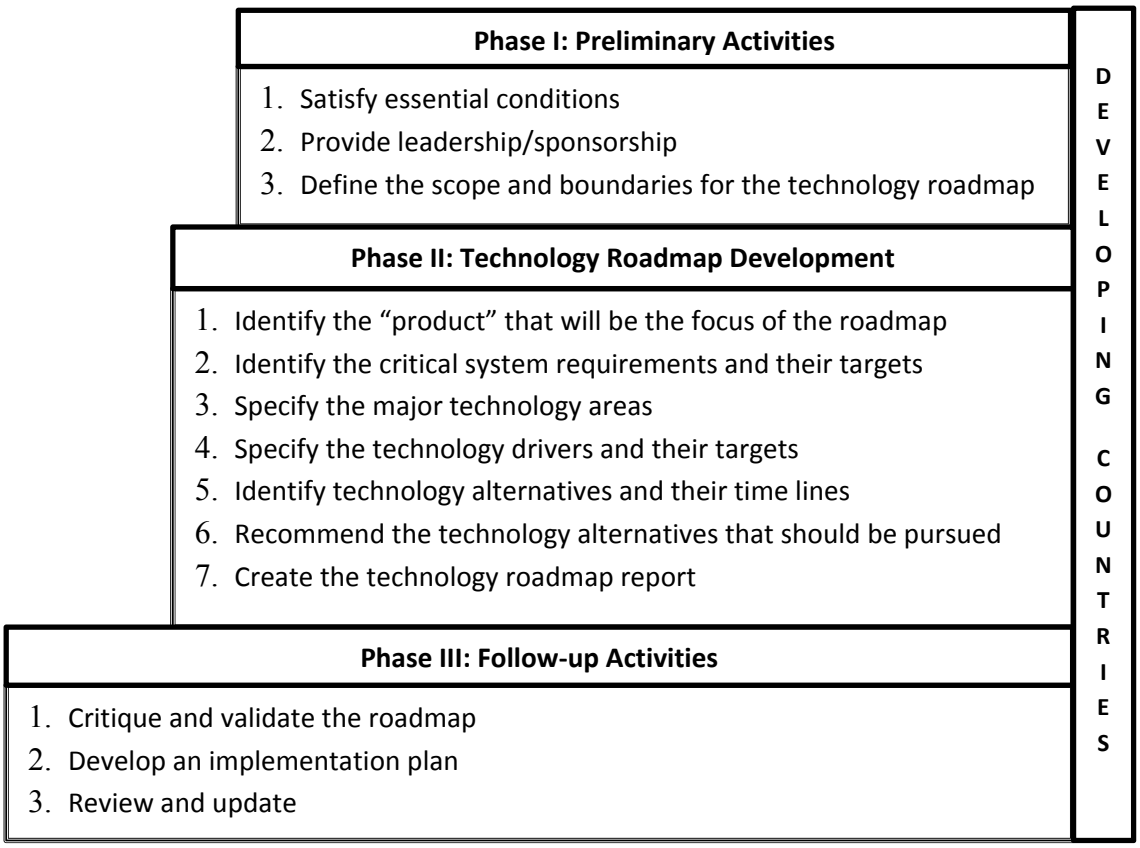

Figure 1. The Three phases in the Technology Roadmapping *Process.*
Adapted from Garcia and Bray (1997)

The research methodology that is used in this paper includes a literature review of each of the three technology roadmapping phases in relation to developing countries' innovation environment and it is exploratory at this stage. As suggested by McDowall (2012) for transition technology roadmaps, the quality parameters that are used in evaluating the resulting technology roadmapping framework for developing countries are that of credibility, desirability, utility and adaptability. The credibility criteria is based on sound analysis (accuracy and completeness of information used for decision making); availability of the right breath of expertise in roadmapping team; participation of and commitment of key actors in the innovation system; and adequate addressing of political, social and economic aspects of the transition. A desirability criterion is based on meeting social goals established through democratic institutions; and giving a clear account of the justification for the proposed pathway (which include information on technology roadmapping objectives, processes followed and participants for each session).

Another quality criterion for technology roadmaps is their utility which is achieved through effective articulation of a path forward that that can enable alignment around common goals and appropriateness of technology roadmapping approaches for the stage of innovation system maturity. Lastly, an adaptability criterion demands that roadmapping processes do involve periodic reviews, updates and learning which can be achieved through embedment within a broader institutional structure that enables flexibility and learning.

TECHNOLOGY ROADMAPPING PROCESS FOR COMPLEX INNOVATION SYSTEMS

Technology Roadmap Format

A simplistic generic technology roadmap output format has been the reason for increasing wide popularity in using the technology roadmapping techniques in long range technology planning. However, for complex innovation systems in need of transition from poor global competitiveness to mainstream innovation, there are other key issues that need to be incorporated into the technology roadmapping format as shown in figure 2. This proposed technology roadmapping format is derived from Genus and Coles (2008) and it incorporates key transition management phases on the horizontal axis. These key components of transition as stated by Van Der Brugge, Rotmans and Loorbach (2005) are predevelopment of innovation niches, take-off, acceleration and stabilisation phases. These resemble the life cycle phases of development, introduction, growth and maturity.

During the predevelopment phase, networks and partnerships are important. Technology sources can either be in-house or outsourced and the same goes for manufacturing capability. This phase communicates to the stakeholders the innovation niches that will be experimented in order to derive the knowledge of what works and what does not work. The niche innovations are shown along with the dominant innovation value-chain within the industry or globally in order to benchmark and to deduce plausible future technological path in business-as-usual environment.

A parallel roadmapping effort that also considers the dominant innovation value-chain is useful for technology planning purposes based on the fact that this represents the best available technology product platform preferred by customers prior to the transition point. On the initial version of technology roadmap, an emergent innovation value chain can represent the ideal emergent innovation standards that are necessary to effect a successful transition. From the knowledge gained during the predevelopment phase, this roadmap can be updated for the take-off and transition phases. The transition point is where the transition takes place during the acceleration phase.

Foresighting of the innovation landscape components (legislation, society, environment and economy) can inform the dynamics that will take place in the future between the emergent innovation value-chain in comparison to the dominant innovation value-chain.

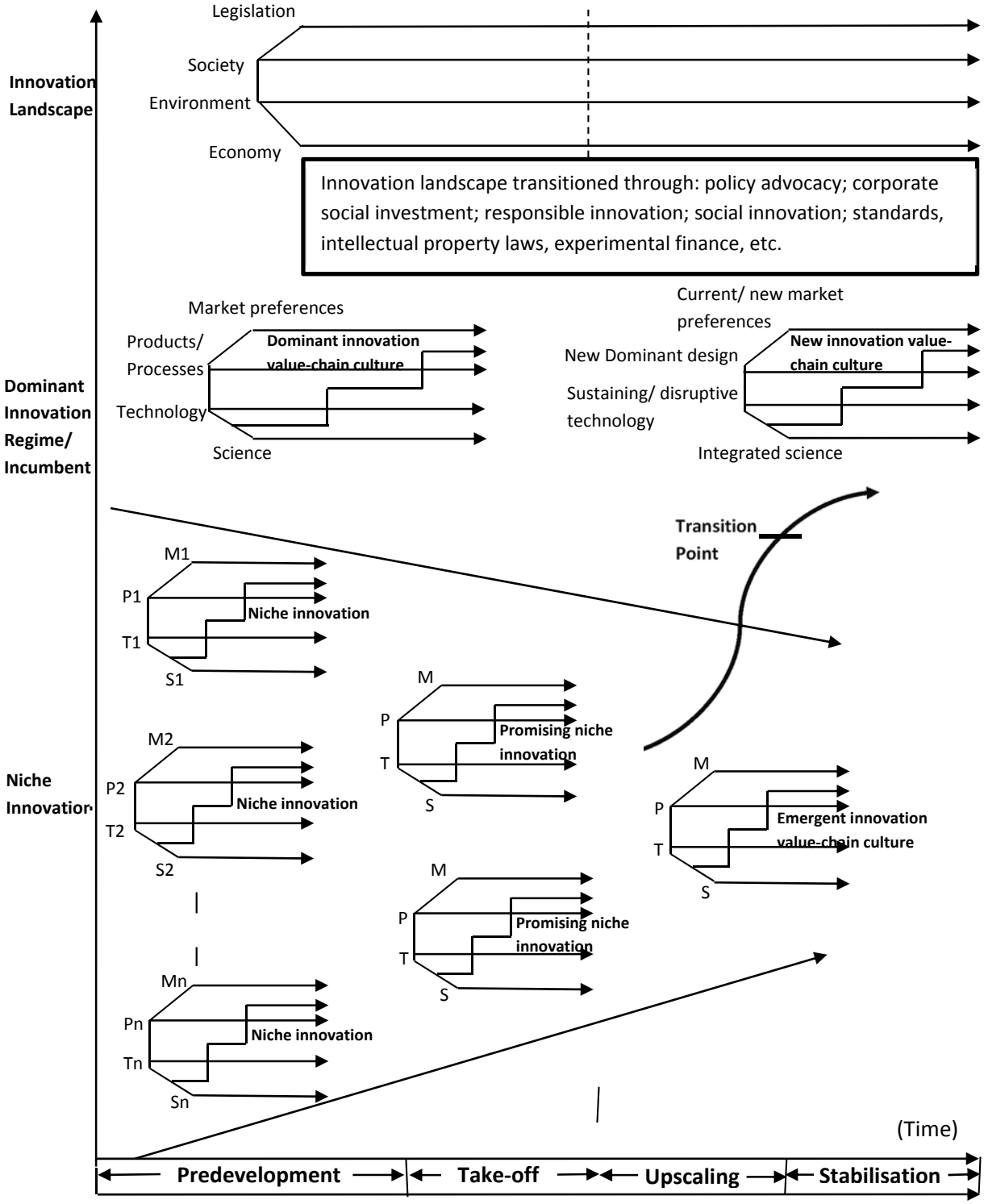

Figure 2. Format for Roadmapping Complex Innovation Systems.
Adapted from Genus and Coles (2008)

Technology Roadmapping Approach

The technology roadmapping process that is aimed at transitioning very complex innovation systems, such as those in developing countries, is a complex issue on its own. A format presented in figure 2 simply summarises an outcome of the roadmap and there are vast amounts of analyses, discussions and workshops that need to take place prior to that to achieve this consolidated vision. As noted by Phaal, Farrukh and Probert (2004) "technology roadmaps are deceptively simple in terms of format, but their development poses significant challenges". We use the generic technology roadmapping framework as a frame of reference to define key activities that need to take place prior to the roadmapping effort (preliminary activities), during the development of the technology roadmap and post roadmapping. A modified technology roadmapping methodology for disruptive technologies contained within Walsh (2004) has ideal concepts for roadmapping in developing countries' environment where there is a scarcity of a stable product technology platform based on unique innovation capabilities.

Preliminary Activities

The essential requirements for technology roadmapping effort involve issues such as making sure that there is a sufficient perceived need for a technology roadmap and to ensure participation from a broad range of stakeholders within the innovation value chain that brings different perspectives to this process (Garcia and Bray 1997). The complexity of market, products and technology decisions required in developing countries' environment implies the need to have a very knowledgeable group of stakeholder experts and seasoned practitioners in support of a roadmapping exercise. A key decision to be made is a balance between partners that are heavily invested in the current dominant technology product platform and those that are more flexible in moving towards a new dominant platform. According to Vob, Smith and Grin (2009), transition management efforts tend to be vulnerable towards capture by powerful incumbents of the status quo. At an organisational level, employees need to be actively involved in the development of technology roadmaps as according to Brah and Hunsucker (2000) "their participation promotes creativity, innovation and commitment to the transition".

As an example, a change from an efficiency-driven to innovation-driven paradigm poses a threat to the prevailing success metrics such as productivity and returns on capital which might cloud a potential sociotechnical transition. This is likely to be a case for developing countries where there are established practices such as reliance on imported technologies. The decisions on a choice of stakeholders for technology roadmapping also apply in providing leadership and sponsorship for the technology roadmapping effort. In order for this process to be successful in developing countries, sufficient effort needs to be done to ensure adoption of knowledge based culture which allows the necessary conditions for experimentation and learning (Zack 2003). As it is a case for most technology roadmaps, there should be a roadmapping committee that is responsible to oversee intial technology roadmap development; to monitor niche innovations, evolution of innovation landscape and that of the current sociotechnical regime; and to lead selection and upscaling of promising niche innovations through an update of the roadmap.

A choice of transition management and complex systems theories for the purpose of this technology roadmapping framework partially explains the scope and boundaries on technology roadmap development for developing countries. The vision is to migrate from the provision of subsystems, to

full systems and eventually to full customer solutions; as a country to transition from technology import driven economy to a net exporter of technology; and at an industrial level to achieve the new breakthroughs in terms of products, processes and technology in order to compete successfully nationally and within the global value-chain. Once this transition vision and a move away from business-as-usual activities are clearly articulated, there may be a high probability for consensus and a shared outlook on the future. Since the transition period is around 20 – 25 years (Vob, Smith and Grin 2009), the time horizon on developing countries' technology roadmaps need to be relatively long for a successful transition.

Technology Roadmap Development

The first step in technology roadmap development is the identification of a product that would be a focus of the roadmapping effort. This step is bit complex, especially for complex innovations, example being that for disruptive technologies. Walsh (2004) articulated on this complexity, in which there is no dominant technology product platform that exists. Instead the author suggests identification of promising technology product platforms and identification of grand challenges. These candidate technology product paradigms form part of the niche innovations shown in figure 2, of which their roadmapping needs to be in parallel to that of dominant innovation value-chain regime, an exercise similar to benchmarking. Kim and Mauborgne (2005) use the concepts of 'red oceans' and 'blue oceans' strategies in describing a choice of products focusing on current and future industries respectively. A strategy canvas is introduced by the authors and this maps opportunities resulting from a gap between dominant product/ services offered and customer needs. The benefit of this blue ocean strategy is reduction in production costs and increased customer value, hence a strategy that have huge potential if adopted by developing countries.

At the national technology policy level, there are two policy choices that a developing country's government can adopt to promote technical change, viz.: accumulation and assimilation interventions. Lall and Teubal (1998) state that an experience from East Asian countries shows assimilation based interventions to be quite successful as they emphasise the significance of learning in making public and private investments successful. Accumulation theories assume a sufficient investment in human and physical capital will automatically bring about technical change, and typical indicators that are widely followed are General Expenditure on Research and Development (GERD) and number of researchers per labour force.

This technology roadmapping framework is based on assimilation theories, in which according to Lall and Teubal (1998), they can take a form of selectivity (picking winners), functionality (interventions intended to improve factor markets without favouring particular activities) and horizontal interventions that lie between selective and functional interventions. In a selective policy environment, niche innovations need to prove themselves as a viable alternative in order to be supported by the government for upscaling. The horizontal technology policies (HTPs) according to Teubal (1997) are central to government inducement of technology-based structural change, including those countries with scant pre-existing capacity to identify strategic niche innovations or strategic technologies. According to the author, an objective of HTPs is "functional promotion of socially desirable technological activities and associated management and organisational routines within business enterprises".

In identifying major technology areas, technology drivers and technology alternatives, emerging technologies in a form of disruptive or sustaining technologies are more appealing to the developing countries. These technologies are key for firms and industries within the developing countries to transition themselves from niche innovations to mainstream global innovation value-chain as they carry less burden of economic rent through intellectual property licensing and payment of royalty fees. Emerging technologies that sustain the current technology product platform are more likely to attract resources, although there is a high likelihood that there will be an acquisition bid from dominant market leaders to acquire such technologies before large scale innovation can be realised. A good example is an internet consulting business in South Africa, Thwate, which became one of the first companies to be recognised by Netscape and Microsoft "as a trusted third party for web site certification" (Smuts 2008). According to the author, VeriSign later acquired the intellectual property from Thwate at a price tag of $575 million.

The technology roadmap report in a context of developing countries still serves a purpose of identification and description of candidate products and technology areas; assessment of current technological capacity; identification of critical factors that, if not met, will cause the roadmapping effort to fail; technical recommendations; and implementation recommendations. The main difference here is a greater need for constant update of the assumptions contained within the roadmap as more learning takes place and the innovation landscape becomes more predictable.

Follow-up Activities

Part of technology roadmapping validation is to secure a buy-in from the critical stakeholders, even the majority of those deeply entrenched on a current dominant technology product platform. Their critique and validation of technology roadmaps is useful in addressing possible risks and to fine tune the assumptions contained within the roadmap.

The transition management theory for complex innovation systems advocates for learning-by-doing and doing-by-learning (Farrelly and Brown 2011), hence the implementation plan resulting from the developed technology roadmap (s) needs to have a high degree of flexibility to adapt to the changes in innovation landscape and for the possible response by the incumbents. More importantly, this flexibility allows for a change of priorities as more information becomes available.

The technology roadmaps need frequent reviews and updates in order to stay relevant. The transition based technology roadmaps as shown in figure 2 have certain transition stages that need these reviews and updates prior to large investments or key decisions. A key critical point is between predevelopment and upscaling stages where the decisions need to be made about niche innovations that need upscaling. The roadmapping framework contained within (Walsh 2004) introduces another step as part of the technology roadmap review and update, viz.: seeking of transition timing to the new innovation value-chain culture.

CONCLUSION

The technology roadmapping process and format presented for developing countries seems to be ideal to address the complexities encountered with regard to innovation planning in technology catch-up situations. As opposed to the reductionist approaches that are based on conducive environments for innovation, the approach selected recognises developing countries' complex interactions that are taking place at systemic level, but also aligns well with the 6th generation

innovation model that is based on knowledge and connectivity. In a traditional technology roadmapping approach, the innovation landscape is compressed on a market layer in a vertical scale of a generic technology roadmapping format. The suggested technology roadmap format achieves a goal of networked and knowledge based organisation by providing information on broad innovation landscape components, future prospective of current incumbents and alternative futures for niche innovations.

The roadmapping approach suggested doesn't explicitly state how the workshops and different consensus seeking discussions should be conducted as it only lays the foundation of key issues for consideration during the roadmapping exercise for developing countries' environments. Potential future research resulting from this work is to refine the conceptual framework through a set of propositions that can later be validated and tested empirically. Various industrial sectors can experience the transition in different ways, hence it will also be vital to validate this proposed framework in several key economic sectors.

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