National innovation systems a proposed framework for developing countries

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Abstract: The concept of a national innovation system (NIS) has been gaining popularity as a core conceptual framework for analysing technological change, which is considered to be an indispensable foundation of the long-term economic development of a nation. The needed infrastructure components for an effective NIS pose a challenge to many developing countries. Therefore, the successful experiences of newly industrialised economies are investigated to explain the divergent evolutionary patterns among these distinct national innovation systems. This paper focuses on synthesising a conceptual framework suitable for adoption by developing countries. The proposed framework might guide developing nations in designing national innovation systems that would help them manage the technological innovation process in a more systematic way.

Keywords: national innovation systems; developing countries; technological development; technology transfer; framework.

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1 Introduction

Technological innovation has been a well-established source of economic prosperity and competitiveness. In the effort to manage the process of technological innovation, many efforts have been exerted to understand and control the phenomenon. Since the 1980s (see Freeman, 1982; Dosi et al., 1988; Lundvall, 1992; Nelson, 1993), the concept of a national innovation system (NIS) has been gaining popularity as a core conceptual

framework for analysing technological change, which is considered to be an indispensable foundation of the long-term economic development of a nation. Technological innovation is a chaotic process that results from the interaction and integration of many components. To bring order to this chaos, there is a need for a systematic approach to understand the relationships between science, technology and innovation, and socio-economic development. Thus, a healthy way of handling this is through viewing it from a system prospective.

2 National innovation systems

A system is a set of interrelated components working toward a common objective. Systems are made up of components, relationships, and attributes. In a later section, this paper will point out some of the components and relationships of NIS, which are of relevance to developing countries. For now, a general brief description of them will be provided.

Components are the operating parts of a system. They can be of a variety of types: Actors or organisations such as individuals, business firms, banks, universities, research institutes and public policy agencies. They can also be institutions in the form of legislative artifacts such as regulatory laws, traditions, and social norms. *Relationships* are the links between the components. Because of this interdependence, the components cannot be divided into independent subsets. Furthermore, if a component is removed from a system or if its characteristics change, the other artifacts in the system will alter their characteristics accordingly, and the relationships among them may also change – provided that the system is robust. Technology transfer mechanisms could be viewed as part of the relationships in innovation systems. *Attributes* are the properties of the components and the relationships between them; they characterise the system. In other words, the features that are crucial for understanding the system are related to the function or purpose served by the system, as well as the dimensions in which it is analysed (Carlsson and Jacobsson, 1999).

The function of an innovation system is to generate, diffuse and utilise technology. Thus, the main features of the system are the capabilities of the actors to generate, diffuse, and utilise technologies (physical artifacts as well as technical know-how) that have economic value. In this context, innovation systems can be defined in a variety of ways: they can be national, regional, sectoral or technological.

The first widely diffused publication that used the concept of a 'national system of innovation' was the analysis of Japan by Freeman (1987). The concept was firmly established in the innovation literature as a result of the collaboration between Freeman, Nelson, and Lundvall in the collective work on technology and economic theory (Dosi et al., 1988). The concept has been further developed analytically and empirically in Lundvall (1992) and Nelson (1993). The approach has become very established in a very short period of time. It is widely used in academic contexts and also as a framework for innovation policy-making.

NIS has been used to describe the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies. Furthermore, the development and transformation of NIS have been seen as an important way for governments to promote competitiveness of industries and services, and therefore the basis of new technology policies (OECD, 1997, 1999).

2.1 Definition of NIS

National innovation systems are defined as the:

> "… set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provide the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artifacts which define new technologies." Metcalfe (1995)

> "From this perspective, the innovative performance of an economy depends not only on how the individual institutions (e.g., firms, research institutions, universities) perform in isolation, but on how they interact with each other as elements of collective system of knowledge creation and use, and on their interplay with social institutions (such as values, norms, legal frameworks)." (Smith, 1997)

NIS can be considered in terms of six basic sub-systems:

- science and technology policy
- innovation strategy
- technical human support services
- technical support services
- mobilising financial resources
- international cooperation.

When each of these sub-systems is strengthened at the national and company (firm) levels, the movement towards transformation to make the knowledge economy work for all can gather momentum (Lalkaka, 2002).

A survey of national innovation systems in 15 countries, large and small, high- and low-income conducted by Nelson (1993) summarises the basic features that are typically common to effective innovative performance, and are lacking where innovation is weak. The main characteristics of the firms in sectors where a country is strong are:

- high competence on what affects their competitiveness, with the main efforts made by themselves. They may be large, but many are small as in Italy, Taiwan and Denmark
- firms are exposed to strong competition, in their own countries and abroad
- effective interactive linkages with their upstream suppliers and customers
- conditions that promote exports force firms to innovate; otherwise, they remain stagnant and seek protection in home markets
- public funding of research in universities and government laboratories in specific sectors of national concern, with results linked to business

A more detailed description and analysis of NIS can be viewed in the material listed in the references section below. The focus of this paper is on discussing features of NIS that are more relevant to developing countries. It will first present some of the research, which focused on NIS in three newly industrialised economies (NIEs). The paper will then attempt to synthesise a framework for developing countries.

3 NIS in developing countries

The notion of NIS has been developed from the background of advanced economies. Frequently, scholars have found that there are many differences between various nations in the way they create and adopt innovations and in the skills and capabilities that exist for bringing about technological change. Developing countries are less developed in terms of institutional composition, sophistication of scientific and technological activities, and linkages between organisational units. Hence, NIS in these countries should play a different role than in developed countries. NIS in developing countries should serve as a purposeful strategic management for catching up, which has been a common focus of newly industrialised economies (NIEs) in the past (Gu, 1999).

The successful paths that NIEs took for rapid technological catch-up has been well researched and documented (see Dhalman and Nelson, 1995; Wong, 1999; Mowery and Oxley, 1995). The research showed many lessons that developing countries could learn from. The findings indicate that countries such as Finland, Ireland, South Korea, Taiwan, Singapore, Brazil, Chile, and Turkey have followed different NIS models that involve a different mix of company strategies, innovation network structure, and state intervention roles. The lesson for developing countries is not to emulate a specific country, but rather to create a dynamic NIS, which best exploits, its unique resources to serve its development purposes at different periods of time. The author believes that the best method for explaining the divergence concept is by presenting case studies of three countries that had relatively similar economies and are in the same region.

3.1 The model of Taiwan

Wong (1999) describes the path that Taiwan took, and the NIS, which supported it as the 'Reverse Value Chain'. In essence, this technological capability development strategy involves starting with first developing process capabilities, followed by later extension into product design capabilities and finally new product creation/branding activities. This is a reversal of the normal sequence of value chain activities pursued by large, established high-tech firms in advanced countries.

Most of the Taiwanese firms that pursued the Reverse Value Chain strategy started as SMEs engaging in labor-intensive manufacturing activities. Because of their limited resources, they were unable to invest much R&D efforts. Hence, the state played an important role in diffusing process technologies to the SMEs through public research institutes (PRIs) in the early stage, and in a later stage through the establishment of various product technology consortia (Wong, 1995, 1999).

Shyu and Chiu discussed the role that government innovation policies played in advancing Taiwan's competitive advantage in more detail. The authors described how tools such as: alleviation of taxation, loan subsidy, technological assistance, government procurement, and cultivation of manpower has increased incentives, based on supply side and demand side, and environment side (Shyu and Chiu, 2002).

3.2 The model of South Korea

In contrast to Taiwan, the Korean innovation system model is characterised by the existence of large conglomerates, the chaebols. Their large size and ready access to finance give them the 'deep pockets' to undertake the Reverse Product Life-Cycle

strategic route. This can be seen in the rapid technological catch up of the large Korean chaebols in such sectors as automobile, steel, consumer electronics, semiconductors (especially DRAM), and Active Matrix LCD. In all these cases, the large Korean chaebols have moved aggressively from late-followers to fast followers, and in the case of DRAM technology, to become the global technological leaders overtaking the USA and Japan (see Kayal, 1999). To achieve their rapid catch up via this strategic route, Korean firms have resorted to aggressive capacity investment to accelerate the learning effect, accepting thin margin or loss bearing to build volume and gain market share, and deep investment in R&D (Cho et al., 1988; Wong, 1999).

After huge state investments in education and public Research and Technology Organisations (RTOs) during the 1960s and 1970s to increase the supply side of technology, the industrial sector had a very low demand for R&D despite the government's strong encouragement and incentives. In other words, the supply of R&D and the linking mechanism was present but the demand side was missing. The linking mechanisms were largely ignored by industries due to the absence of a clearly felt need to invest in R&D given the relatively easy means of acquiring and assimilating foreign technologies then available from many sources. It was only in the 1980s, when technology was regarded as one of the most important underlying variables in market competition that the situation changed. To fix this short fall, the government then introduced new policies designed to strengthen industry's need for R&D. One of which was a list of import-substitution of major import items. That is, the government designated specific target machinery, parts, and new materials that should be localised for import-substitution. It then offered tax incentives, preferential financing, and R&D subsidies to those who develop the designated items. Through 1987, the government has designated 1,555 such items (Kim and Dahlman, 1992).

3.3 The model of Singapore

In contrast to Taiwan and Korea, Singapore adopted a model of a national innovation system that can be best characterised as one emphasising government facilitation of technological learning from Multi National Corporations (MNC). Ever since the government embarked on a strategy of encouraging foreign investment to jump-start industrial development in the 1960s, the Singapore government has continued to encourage MNCs to upgrade their manufacturing processes and to bring in successive waves of new and more advanced products to be manufactured in Singapore. Research evidence has shown that these MNC operations have spawned a large supporting industry in Singapore and induced substantial technological capability development among many local subcontracting and contract assembly firms. This was also facilitated by the movement of experienced technical professionals and managers from the MNCs to start up their own contract manufacturing firms (Wong, 1997).

Although the Singapore government established PRIs to promote the diffusion of process technologies to local small and medium size enterprises (SMEs), it has probably done less in facilitating the diffusion of product design know-how than Taiwan and Korea.

To support a shift to another route of technological development, the government has accelerated the establishment and funding of PRIs/university R&D to encourage MNCs to start product R&D operations in Singapore and recently, launched an ambitious Technopreneurship Program to promote the growth of new technology start-ups.

Besides promoting the development of new supporting infrastructure such as a venture capital industry and IPR support services, the government is reviewing changes to existing business regulations (e.g., stock exchange listing regulations, stock option rules and tax incentives for business angel investment) to facilitate the growth of technopreneurship (Wong, 1999).

4 Issues to address in NIS for developing countries

4.1 Government's role

Kim and Dahlman (1992) suggest that public policies to promote science and technology are a major driver in developing countries. Public policies may be categorised into three components:

- policies designed to strengthen the supply side, increasing science and technological capabilities
- policies designed to strengthen the demand side, creating market needs for technology
- policies designed to provide effective linkages (technology transfer) between the demand and supply sides, attempting to induce and make innovation activities successful technically and commercially (Kim and Dahlman, 1992).

4.2 Technology transfer

A country's NIS comprises the network of public and private institutes that fund and perform R&D, transfer the results of R&D into commercial innovations and effect the diffusion of new technologies. The experiences of Asian NIEs have drawn attention to the role of NIS in supporting the inward transfer and exploitation of technologies from external sources. The exploitation of external technology requires the creation of some 'absorptive capacity' at the firm and national levels. Absorptive capacity is the ability to understand an externally sourced technology and apply it internally. In order to do this, firms must maintain some research capacity (Mowery and Oxley 1995).

Different modes of technology transfer (such as licensing, joint venture or direct transfer of a wholly-owned subsidiary) place different demands on the absorptive capacity of the recipients. Furthermore, most technologies consist of codified and tacit knowledge. International (or domestic) transfer of technology requires access to the tacit components as well as those codified in a blueprint, license agreement or data package. In order for a developing country to gain access to the tacit knowledge they would have to either transfer people who embody the knowledge from abroad, or go through technological learning by reverse engineering and competitive intelligence methods. South Korea's success in technology transfer was largely attributed to its public R&D centers which developed new technologies for the private sector through reverse engineering foreign technologies especially when those foreign firms refused to license advanced technologies to Korea (Kim, 1991)

4.3 Absorptive capacity and technological learning

In order for a developing country to gain economic strength it must start by understanding its competitive advantage, weaknesses, and strengths. It must also understand the process by which countries acquire indigenous capacity to create, manufacture and market new product and process innovations. NIS of developing countries should be designed to first build up the local firms' capacity to absorb, adapt and apply new technologies from abroad. Eventually, as firms become more advanced, and indigenous innovation is established, NIS should support the use of locally developed technology and technical expertise to create products, processes, and services that compete successfully in international markets. Building absorptive capacity in science and technology has been recognised as the most challenging aspect for NIS (Roessner et al., 1992; Mowery and Oxley, 1995; Porter, 2003).

It is worthwhile to note that, policies related to technology promotion may be conceived and implemented in a short time span, but manpower development can only be built through long-term planning and investment. In this sense, developing countries should start investing for human resource development early enough for subsequent industrialisation and technological development. Absorbtive capacity and technological learning are not merely education and training for scientists, engineers, and technicians. The concept extends to include research and experimental development, and reverse engineering.

5 NIS Framework for developing countries

Conceptual frameworks for technology management and innovation support understanding of issues, provide structure, and support decision making and action (Phaal et al., 2001). This paper proposes a conceptual framework consisting of system drivers, components, boundaries, and integration. The framework might be useful for developing countries to consider when designing their NIS. The proposed NIS framework is a synthesis of various research recommendations adapted to fit the author's views. Discussion of the framework is presented below, and is schematically presented in Figure 1 and Table 1.

Figure 1 Framework of NIS for developing countries

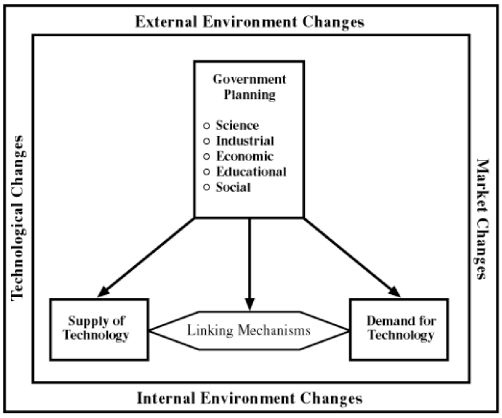

Table 1 Components of the framework for NIS for developing countries

Components	*Drivers*		
	Supply of technology	*Linking mechanisms*	*Demand for technology*
Planning	S&T polices	Technology foresights	Import substitution policies
	Innovation strategies	Technology transfer polices	Technology roadmaps
Infrastructure	Public and private research and technology organisations (RTOs)	Intellectual property protection	Competitive domestic markets
	Higher education institutions	Technology parks	R&D culture
		Technology incubators	International markets for products and services
		Industry associations	
		R&D consortia	
		Technology transfer organisations	
		ICT infrastructure	
Resources	Public R&D funding	Seed capital	Entrepreneurs
	qualified scientists, engineers, technicians	National invention support programs	venture capital
		National industrial support programs	specialised credit facilities
		Mobility of people and expertise	

5.1 Drivers of the system

The framework draws an analogy from the basic economic model of supply and demand and consists of three drivers:

- supply of technology
- demand for technology
- linking mechanisms.

The proposed general framework, also prescribes a government planning function, which sets high-level policies designed to support the major drivers of the system.

5.2 Components of the system

The three major components of the system are planning, infrastructure, and resources for technological innovation. *Planning* refers to any kind of strategic planning, at the national or firm level, which supports the three drivers of the system. *Infrastructure* refers to any structural elements, physical or non-physical, which support the three drivers of the system. *Resources* refer to any resource element (people and money), which support the three drivers of the system. More details of the components are presented in Table 1.

5.3 Boundaries of the system

The boundaries of the proposed NIS framework are its external environment, internal environment, technology, and market. The boundaries of NIS change with time, which is why NIS of developing countries should be dynamic and evolving.

5.4 Integration of the system

Systems of innovation are open dynamic systems where components should interact with each other with a great deal of matching efficiency between them. Some NIS comprise of institutions that create knowledge, while others distribute and utilise knowledge. The success of NIS resides in the degree of integration and matching efficiency between the various drivers and components of the system.

6 Using the framework: case of Saudi Arabia

As a case study of how the framework could be used to assess the status of a NIS in a particular country the author used the information about science and technology gathered in the Kingdom of Saudi Arabia and then transformed it in the proposed framework to present a snapshot of the status of NIS is Saudi Arabia. The exercise was presented as a guideline of how the framework could be used in the future. The status of NIS in Saudi Arabia was summarised in Table 2.

Table 2 Status of NIS in Saudi Arabia

Components	*Drivers*		
	Supply of technology	*Linking mechanisms*	*Demand for technology*
Planning	S&T polices (Government just approved the policy in 2002)	Technology foresights (not used)	Import substitution policies (does not support technology industries)
	Innovation strategies (in progress)	Technology transfer polices (not developed)	Technology roadmaps (not used)
Infrastructure	Public and private research and technology organisations (RTOs) (five institutes are active)	Intellectual property protection (Patents system operating but slow by international standards; Trade secrets protection law passed in 2005; Copy right protection is being enforced aggressively very recently)	Competitive domestic markets (exists but dependent on foreign technologies)
	Higher education institutions (three institutes are active)	Technology parks (three at planning stage)	R&D culture (very weak)
		Technology incubators (three at planning stage)	International markets for products and services (weak especially in medium and high tech products and services)**

Table 2 Status of NIS in Saudi Arabia (continued)

Components	*Drivers*		
	Supply of technology	*Linking mechanisms*	*Demand for technology*
		Industry associations (non)	
		R&D consortia (non)	
		Technology transfer organisations (one society)	
		ICT infrastructure (ranks low according to international standards)*	
Resources	Public R&D funding (very weak)	Seed capital (one organisation offers it but its not focused on technology industries)	Entrepreneurs (weak)
	Qualified scientists, engineers, technicians (very weak)	National invention support programs (non)	venture capital (does not exist)
		National industrial support programs (available but not focused on technology industries)	specialised credit facilities (non for technology industries)
		Mobility of people and expertise (weak)	

*Saudi Arabia scores 0.44 out of 1 in Digital Access Index (International Telecommunication Union, 2003).

**High technology exports (% of manufactured exports) Saudi scores (0.35%) which is very low compared to other nations such as Singapore (60.32%). (World Bank databases http://genderstats.worldbank.org/query/default.htm).

6.1 NIS in Saudi Arabia

In Saudi Arabia, the most challenging aspect in establishing a strong NIS is in developing its S&T human resources. With only 15% of its university graduates in 2002 having science and engineering degrees, coupled with a low number of technicians and graduate students this is considered by far the weakest component of the system. The number of scientists and engineers per 100 thousand inhabitant is only (70) in 2001, which is low compared to (383) in South Korea as an example (King Abdul-Aziz City for Science and Technology, 2002).

Another important component of the system is its Research and Development centers (or research and technology organisations RTOs). There is only one public RTO in Saudi Arabia which belongs to King Abdul-Aziz City for Science and Technology. The only other RTOs in Saudi belong to various government owned companies and agencies which are:

- Aramco (one of the largest oil companies in the world)
- Saudi Basic Industries Corporation (SABIC) who also has R&D centers for petrochemicals in Houston and India
- King Fisal Specialist Hospital (for medical research)
- salt water desalination authority.

The only major university related research institute in Saudi belongs to King Fahd University for Petroleum and Minerals, although other larger universities do have research offices which coordinate industry-university research. The private sector in Saudi has no R&D facilities to count for. As a whole, the total R&D funding in Saudi accounts for only (0.25% of GDP), which is considered very small compared to other developing nations.

In terms of policies, the country has recently passed its first long term national science and technology policy in 2002 and work is currently being undertaken to translate it into strategies, programs, and detailed projects. The most important goals of the S&T policy is to raise the national R&D funding, and to increase the number of scientists, engineers, and technicians in the country. An industrial strategy is also currently being developed with the assistance of UNIDO and it is expected to be finalised by the end of 2005.

Regarding the infrastructure for S&T, Saudi Arabia has established most of its intellectual property right systems; nevertheless much work needs to be done in terms of enforcing them. The most challenging infrastructure to establish in Saudi will be physical infrastructures such as technology parks and incubators, which do not succeed without well established support programs for high-tech industries and SMEs that the country currently lacks. Nevertheless a new public agency was created (Saudi Organisation for Industrial Estates and Technology Zones) to regulate and promote the establishment of technology zones in the country.

In general, the NIS in Saudi Arabia is considered in the process of catching up in all the components and drivers of the system. The system's weakest area is considered to be the demand side of the drivers of the system. After developing the needed infrastructure and establishing strong demand for technology, the country’s next challenge is to establish a strong linking and integration mechanisms for the whole system.

7 Conclusions

This paper offers a conceptual framework for NIS in developing countries. The framework is intended to incorporate a number of key principles that underpin technological innovation in developing countries. The framework was synthesised from various studies and research on Newly Industrialised Economies namely South Korea, Taiwan and Singapore. Developing nations face greater challenges in technological development. Insufficient industrial and technological infrastructures, and poorly established education systems pose a disadvantage. Key lessons could be learned from the experiences of NIEs. The most important dimension that developing countries should consider is the inward transfer and exploitation of technologies from external sources through building absorptive capacities. Another important dimension is the degree of integration of the components of the system. Technological innovation is a complex process that requires instituting, managing, and interacting many subsets and activities. The proposed framework might guide developing nations in designing National Innovation Systems that would help them manage this process in a more systematic way. Future work using the proposed framework will be to use standard international indicators (that measures S&T-competitiveness-innovativeness-infrastructure etc.) for each element in the framework and then mapping out NIS of a benchmark country such as Finland (a developing country which is considered the second most innovative country

in the world Porter 2003). After a benchmark is set the framework could then be used in comparing various less successful countries to the benchmark in order to identify gaps and weaknesses.

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