Neo-Schumpeterian Technological Change and the Role of National R&D in Technological Learning

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1. Introduction

Through the improvements in capital and labour productivity, the creation of new products, services and systems (Mitchell, 1999), technological progress has been acknowledged to be the major determinant of industrial development (OECD, 1996; Kim, 1999) and national economic growth (Rosenberg, 1982; Nelson and Winter, 1982; Patel, 1995) in both developed and developing countries.

Since the late 1970s, the concept of technological learning has been addressed to explain technological change in developing countries (Fransman, 1984; Gonsen, 1998). The technological learning school finds the source of successful economic growth in developing countries, especially Newly Industrialising Countries (NICs), [1] in the technological efforts made in the course of acquiring and improving their technological capabilities. This school recognises that, with the active technological effort involved in technological learning, developing countries can efficiently import foreign advanced technology and effectively develop local technological capabilities (TCs), which contribute to their industrialisation and economic growth.

This technological learning in developing countries has been amply documented with respect to private firms (Bell, 1984; Dahlman and Fonseca, 1987; Enos and Park, 1988; Lall, 1992; Hobday 1997; Kim, 1999). Nearly all the literature on technological learning in developing countries has focused on the firm while placing firm technological activity for production at the centre of technological change and as the major driving force of economic development.

This firm-focused literature has some limitations while it addresses generally R&D to distinguish the innovation stage from the earlier absorption and adaptation stages (Fransman, 1984; Dahlman and Foneseca, 1987). In particular, national R&D programme, which is defined as an R&D programme administered by the government,

[1] They are South Korea, Hong Kong, Singapore and Taiwan.

has been more or less recognised to play a co-operative role in strengthening firms' TCs and in turn their international competitiveness as an external source of knowledge and technology (Kim, 1997, Kim and Yi, 1997).

However, technological learning might be lead by national R&D, in particular under the context of inadequate TCs of industrial firms and academic research. For instance, TCs building in the Korean nuclear fuel occurred mainly under national R&D programmes undertaken by government research institutes (GRIs). Korea Atomic Energy Research Institute (KAERI), a GRI, carried out national R&D projects to localize foreign technology for commercial purpose and develop TCs for domestic industry. From the early 1980s, two consecutive national nuclear R&D projects have been devoted to the development of TCs for CANDU-type nuclear fuel with a view to achieving national goals of developing domestic industry (diffusion-oriented). As of the end of 2001, TCs in CANDU fuel is reached to international technological frontier with developing an innovative technology in global sense after localization of the conventional mature technology in 1980s. In the light of technological change, national R&D has developed domestic TCs and contributed to establishing and developing domestic industry.

Therefore, this article aims to provide a theoretical base to identify the role of national R&D in the Neo-Schumpeterian technological learning, which is compared with the conventional firm-focused literature. As long as technological change in developing countries is recognised as an endogenous process of incremental change starting with international technology transfer, two basic theoretical alternatives are investigated to explain the growth of TCs in developing countries: neo-Schumpeterian economics and technological learning. Section 2 reviews the characteristics of neo-Schumpeterian technological change for technological change in developing countries while comparing it with the neo-classical economic theory. From a neo-Schumpeterian perspective, Section 3 draws key feature of technological learning approach. The basic concept of technological learning is compared with dependency theory. In section 4, technological learning path is reviewed, which is necessary to explore the role of national R&D in technological learning in Section 5. Section 6 provides conclusion of this article including further application of the findings.

2. Neo-Schumpeterian Technological Change against Neo-classical Economics

Neo-Schumpeterian economic theory emerged from the notion of the limitation of neo-classical economics that lacked the role of technology innovation in economic activity. Neo-classical theory does not explain the improvement of productivity that

results from technological change by the recipient of externally supplied technology. The theory supposes that a specific technology can be codified and, if followed precisely, will lead to a specific result (Nelson, 1987). In neo-classical economics, as Nelson (1987) pointed out:

> … technology is viewed as explicit and articulated, imitable and teachable, and embedded in a broad body of understanding which permits previously unused variants to be reliably readied for use. (p. 83)

In this neo-classical view, a specific technology is selected on the basis of profit maximising calculus. New production function is made by reflecting the change of factor intensity resulting from the selected technology, e.g. increases in capital and other resources per worker (Nelson, 1987).

Being thus highly simplified, the theory regards technology as being freely available to all economic entities concerned in the technology transaction. Therefore, neo-classical theory ignored the role of technological change performed by recipient's technological effort. Following this neo-classical view, developing countries can receive all relevant technologies from advanced countries. The theory does not consider the technological effort of the recipient needed to absorb and adapt the technology for the increase of productivity. The theory excludes the possible development of endogenous TCs in developing countries. That is to say, it does not explain technological change as a result of technological effort in developing countries (Lall, 1992).

In contrast, the neo-Schumpeterian view acknowledges technological advancement to be the central force in the economic phenomena: productivity growth, competition among firms in industries, international trade patterns, and so forth. In explaining the relationship between technology change and economic phenomena, this neo-Schumpeterian is interested in the evolutionary nature of technological change (Nelson and Winter, 1982). Technological change is viewed as an evolutionary process of technically-diverse solutions and selection mechanisms to substitute for less-desirable technologies in terms of cost advantages, technical superiority and evolutionary potential (Arundel *et al.*, 1998; Girifalco, 1991).

So far as technological change in developing countries is concerned, there are two important characteristics of the neo-Schumpeterian view: incremental technological change and tacitness of technology.

First, the neo-Schumpeterian regards the process of technology development as an incremental and cumulative process. Assuming that technological change are path-dependent, i.e. highly specific to particular categories of industrial products and

processes, prior accumulation of technological experience and performance is very likely to provide the basis for the development of current and future technological change (Fransman, 1984; Bell and Pavitt, 1993).

The neo-Schumpeterian follows Schumpeter's view of the relationship between technological change and economic development. Like Schumpeter, the neo-Schumpeterian view acknowledges that technological change is one of the endogenous determinants of economic development. However, the neo-Schumpeterian stresses the importance of incremental rather than radical innovation. Schumpeter focuses on the radical change that refers to the deployment of discontinuity of radical innovation to expand the international technology frontier. In contrast, the neo-Schumpeterian views technological change as an evolutionary process in which the incompleteness of the original breakthrough is successively improved by a series of complementary innovations in product or process technology rather than one major event resulting from an original breakthrough of radical innovation.

This neo-Schumpeterian emphasis on incremental technological change does not mean either that technological change is achieved only by the accumulation of incremental change or that radical change is not important in technological change. Rather, it stresses the importance of incremental change over radical change in understanding technological change as the process of integration of technological discontinuity by radical change with continuous accumulation of incremental change (Kim, 1994).

Starting with the introduction of discontinuous technological change mainly through exogenous international technology transfer, technological change in developing countries is assumed to occur incrementally and cumulatively through endogenous technological activities. Hence, the neo-Schumpeterian perspective of incremental technological change could provide the conceptual basis to explain technological change in developing countries, especially NICs.

Second, the neo-Schumpeterian notes the tacit nature of technology. The tacit nature of TCs comes from the notion that it is not possible to completely codify technology (Nelson, 1987; Bell and Pavitt, 1993, Najmabadi and Lall, 1995). The importance of this notion lies in the fact that technology might not be easily transferred from the supplier to the recipient, imitated or taught in its entirety in any transfer.

To the extent that technology is tacit, technology transfer involves a significant degree of uncertainty, particularly where a considerable division of labour and organisational process are involved (Nelson, 1987). In international technology transfer, therefore, the recipient faces numerous technological problems to which the supplier does not offer answers. Under the very different conditions of technological change

between the supplier and the recipient, i.e. technological capabilities and technological environment, these problems are more likely to be accentuated in a North-South technology transfer. Likewise, the initial acquisition and subsequent transition of technological capabilities from lower to higher stages are not accomplished automatically or costlessly. These natures of TCs require purposeful technological effort with a successive commitment of considerable time to monitor technological environments, to make effective use of imported technology and to accumulate and improve TCs. In accepting this neo-Schumpeterian view of technology, imported technology is not completely understood in the course of the technology transfer and is only mastered as a result of the technological effort made by the recipient to effectively utilise the transferred technology. Thus, the neo-Schumpeterian perspective of technology needs to be acknowledged in explaining how developing countries perform technological change through endogenous technological effort as well as international technology transfer.

3. Technological Learning Approach against Dependency Theory

This notion of technological learning defies the so-called dependency theory in terms of technological capabilities and international transfer. Dependency theory focuses not only on the existence of an international imbalance in technological capabilities but also on the reproduction of the imbalance (Kim, 1994). According to Stewart (1978), the imbalance of TCs between the centre and the periphery arouses the relationship of technological dominance-dependency in which the technology monopoly at the centre constrains endogenous TCs development in peripheral countries. Under this unbalanced relationship of technological division of labour, developing countries lacking domestic TCs continue inevitably to depend on the foreign advanced technology and this vicious cycle of dominance-dependency between the North and the South is reinforced.

This dependency theory does not take into account the role of endogenous TCs as a way of economic development in developing countries. While regarding international technology transfer as a supplier-dominated process between the centre and the periphery, it confines the technological effort of the recipient to the selection of technology. That is to say, the theory does not explain the endogenous technological change of developing countries through international technology diffusion.

In contrast to dependency theory, the technological learning school tries to explain the endogenous process of TCs building in developing countries. In extending neo-Schumpeterian perspective on technological change to the developing countries, this

school finds the answer to the question of how the imported foreign technology leads to technological change by the recipient in developing countries.

According to Bell *et al.* (1984), the failure of firms in DCs to achieve and maintain international competitiveness, such as the successful transition from the infant to the mature stage, resulted from the absence of continuous technological effort to acquire and utilise TCs necessary for technological change. Amsden (1989) related the success of Korean industrialisation to the progressive process of technological learning while pursuing technological independence and avoiding foreign control. In a comparative study of the technological capabilities of emerging Asian countries, including the NICs, China, etc., Lall (1998) concluded that countries have to develop TCs for sustained growth and technological upgrading.

The school acknowledges that technological capabilities are accumulated in the course of solving the problems involved in absorbing and adapting imported technology, and generating new technology. In the course of problem solving, the technological effort of the recipient could incrementally change the transferred technology and, as a result, TCs will be accumulated and improved. In this view, to the extent that TCs are locally internalised and developed, TCs building is not really seen as the geological movement in the course of international technology transfer and the expansion of explicit technical capacity in terms of production equipment, facilities and plants, etc. Moreover, self-reinforcing technological dependency can be overcome by the development of TCs at the peripheral.

Three important characteristics of technological change of developing countries can be identified in these TCs studies: incremental technological change, international technology diffusion and technological effort. In other words, these studies argue that technology development of developing countries goes through incremental technological change that is triggered by international technology diffusion from industrially advanced countries, and that the performance of these technological activities heavily depends on the technological effort exerted by the developing countries.

From this perspective, technological capabilities are defined as the ability of an organisation to make effective use of technology in absorbing and adapting external technology and generating new technology over time while responding to environmental change (Fransman, 1984; Caillods, 1984; Dahlman and Fonseca, 1987; OECD, 1992; Lall, 1998; Kim, 1999). Technological learning is comprehensively defined as the process of building-up of technological capabilities in developing countries. It refers to the whole set of the endogenous technological activities of the recipient to acquire and develop domestic TCs starting with choice of technology from

the existing foreign advanced technologies (Bae, 1987).

4. Technical Path of Technological Learning

Technological change through TCs building in developing countries is postulated to start with the international diffusion process of specific and matured technology on the product life cycle (PLC) from advanced countries. This perspective on technological change in developing countries leads to a distinction between different courses of technological change from those experienced in the supplier countries (Fransman, 1984).

So far as the PLC model was concerned, Vernon (1966) argued that the innovation pattern moves from product characteristics to production cost through the PLC. Along with this PLC, production location shifts from the US to western European countries, to developing countries while responding to production opportunities to reflect the flexibility of market preferences and production cost (Vernon, 1966).

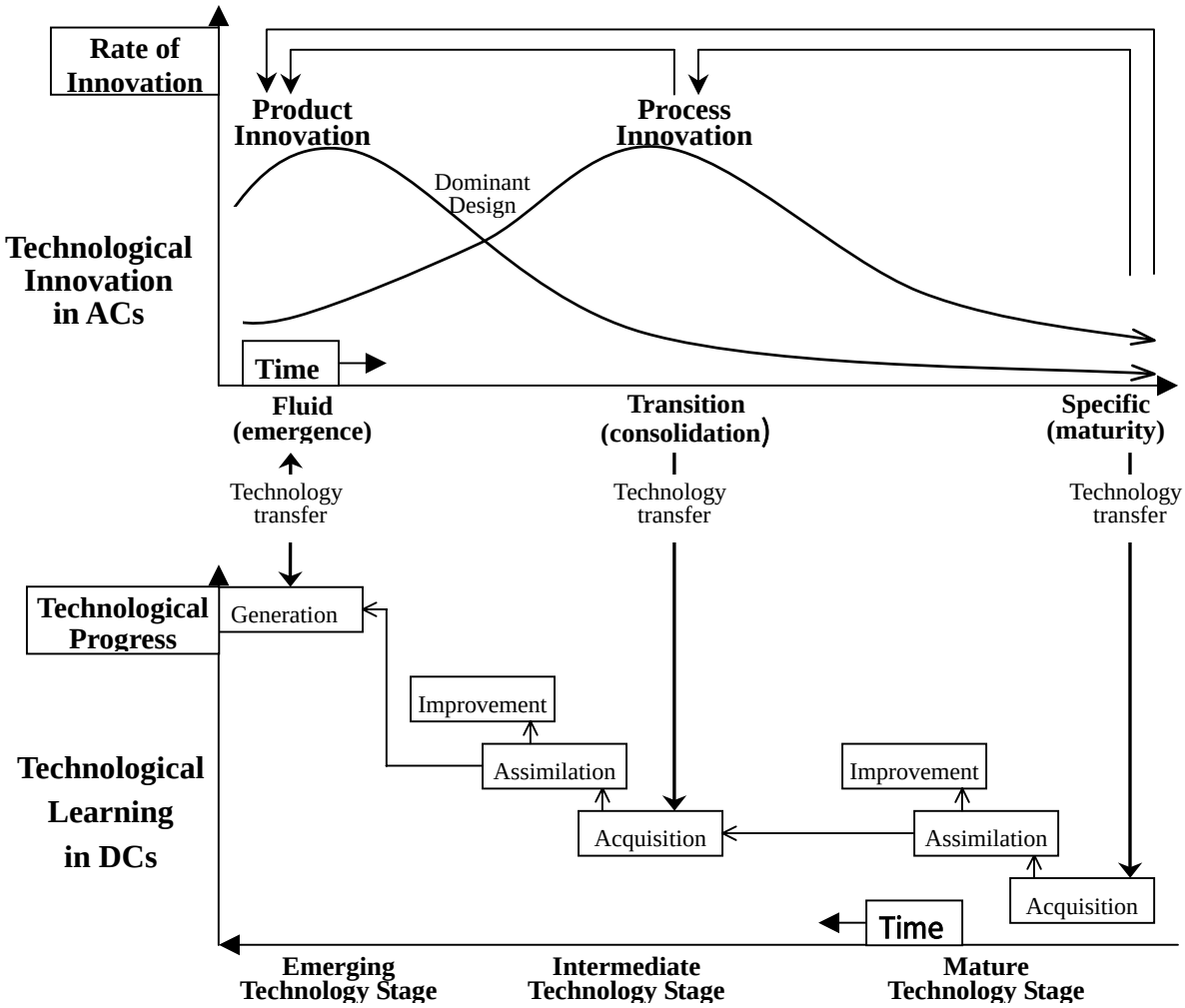
Utterback and Abernathy (1975) linked the phases of the product life cycle to innovation path, industrial competition (number of competitors and basis of competition) and corporate organisation (organisational structure and organisational control). Utterback and Abernathy's product life cycle model offers a better understanding of the patterns of technological change, although the model is not universally applicable to all industries, especially for industries with a differing variety and use of products, or the divergent and specialised customer needs (Utterback, 1979; Nelson, 1998).

According to the model, the path of technological innovation progresses through three phases: fluid, transitional and specific. In the early fluid phase, radical product innovation prevails while an industry is formed. As the dominant design of product emerges, the transitional phase begins. In this phase, major process innovation becomes more important than product development. A very mature and specific product is produced in the specific phase. Product design becomes standardised and process operation becomes automated using lower-skilled labour (Utterback, 1994).

Even though the PLC model is articulated to explain technological change in advanced countries, it is, by and large, used to assume technical path of technological learning in developing countries. With reference to the PLC model, technical path of TCs building is generally recognised as following the pattern of the so-called 'reverse product life cycle (reverse-PLC)' (Hobday, 1997; Kim 1999). Some technologies at the later stage on the PLC model in advanced countries are likely to be linked to the beginning of TCs building in developing countries. Developing countries gradually develop domestic TCs by technological learning through absorbing and adapting the

imported technology and generating new technology.

Following this reverse-PLC model, technological change in developing countries goes from mature and standard technologies to emerging technology and from process to product technology in connection with the technological trajectory from production cost minimisation to product performance maximisation. Moreover, it implies that successful TCs building from absorption to adaptation to innovation requires essentially long-lasting organisational commitment in terms of time, cost and human capital.



Stage	Generation [Innovation]		Acquistion [Absorption]
Novelty	**Emerging Technology**	←	**Mature & Standard Technology**
Locus of Tech. Change	**Product Change**	←	**Process change**
Technological Trajectory	**Product performance Maximisation**	←	**Production cost minimisation**
Complexity	**More Complex & Innovative - Design of Co**	←	**Less complex & Innovative - Manufacturing of light industry articles**
Way of learning	**More Innovative - Learning by R&D - R&D for Indigenous TCs**	←	**Less Innovative - Learning by Doing - Turn-key /Licensing**

(Figure 1) Technical Path of Technological Innovation and Learning[2]

[2] The upper part of figure is borrowed from Kim (1999), while the lower part is concerned with the change of targeted technology, technological trajectory and way of learning summarized by the author.

By incorporating Utterback and Abernathy's PLC model and Lee et al. (1988)'s stage model, Kim (1999) postulated that the technological path of technological change in developing countries proceeds in a reverse direction to the dynamic model as shown in (Figure 1) where summarizes that targeted technology, technological trajectory and way of learning is likely to vary according to technical progress as well.

5. Technological Learning by National R&D

Since there have been few studies on TCs building through national R&D programmes by GRIs,[3] this research draws on the extensive studies of the experience of private firms in reviewing technological learning approach. This does not mean that all the approaches articulated for private firms are equally applicable to the cases of technological learning by national R&D. An appreciation is necessary of the major differences of the role and nature between GRI's national R&D and firm's activities in technological learning to appropriately apply firm literature to national R&D programmes carried out by GRIs.

5.1 Technological Learning by Firms

On the assumption that firms are rational entities in profit-maximising terms, firm's technological learning is generally organised on the basis of evaluating market conditions and technology characteristics, such as market competition, market size, growth prospects, learning difficulties, and so forth. In this evaluation, firm's technological learning projects are mainly determined by the economics of TCs building which depends on the trade-off between investment in and return from TCs building. In this regard, firms tend to develop TCs for the exploitation of existing and potential markets from a relatively short-term perspective.

At the outset of technological learning in particular, firms are likely to make efforts to solve imminent problems in selecting technology and conducting TCs building. In this early stage, firms' technological activities focus on the efficiency of technology acquisition. In the later stages, technological efforts are concentrated on utilising TCs

[3] Throughout this thesis, national R&D represents R&D which is administered by government agencies and largely carried out by government research institutes.

already accumulated. In addition to the efficiency of acquiring TCs, firms begin to consider the effectiveness of TCs and long-term profits, for the purpose of improving potential market competitiveness (Bae, 1987).

Assuming that innovation capability is required after absorption and adaptation for the long-term viability of firms (Fransman, 1984), firm studies emphasise the substantial investment in R&D activity needs for innovation (Bell *et al.*, 1984; Lall, 1987; Dahlman and Foneseca, 1987; Najmabadi and Lall, 1995).

In this regard, R&D barely figures in the beginning and intermediate stages of technological learning. The firm-focused TCs studies pay little attention to learning-by R&D from the earliest stage of technological capabilities building. This study instead focuses on the accumulation of experience in using foreign technology in the production process as the starting point of technological learning in developing countries (Dahlman and Fonseca, 1987; Enos and Park, 1988; Hobday, 1997; Gonsen, 1998). In other words, the firm TCs literature argues generally that developing countries begin their technological learning by accumulating experience in technological problem solving in relation to production performance, and adapting original plant designs to use locally available material and change production capacity. Thus, the firm-focused literature does little consider the role of R&D in spawning the absorption and adaptation stages of TCs. This is because firm-focused studies are likely to adopt the conventional notion of R&D that refers to the generation of scientific knowledge and new technology (Rosenberg, 1982; Cohen and Levinthal, 1989).

However, in looking at R&D in a broader sense as a problem solving process in technological change, it would be part of technological learning from the beginning. To the extent that this problem solving activity generates new knowledge, however minor or organisation-specific, which leads to changes in process and product technologies (Fransman, 1984), technological change through R&D is likely to take place in the absorption and adaptation stages. In addition to expanding the international technology frontier in the firm capabilities literature, R&D could also facilitate absorption, adaptation and improvement of foreign technology while imitating and utilising the external technology (Cohen and Levinthal, 1989; Cohen and Levinthal, 1990; Lall, 1998). In such a way, R&D plays a role in problem solving in the TCs building process and improving the existing TCs stock (OECD, 1997).

5.2 Technological Learning by National R&D

In the firm TCs literature, the role of government has been indirectly regarded to provide a favourable environment for the purposes of facilitating firm technological activities through building infrastructure to ease firm's technological activities, developing institution to attract firm's investment in technology innovation, and promoting technological education and training to develop highly-qualified workforce, etc. 'Learning by research' by government research institutes (GRIs) as well as by corporations and universities is recognised as a dominant pattern of technological change in advanced countries in expanding international technological frontier. In contrast, 'learning by doing' and duplicative imitation by corporations occupy the large attention of firm-focused literature regarding technological capabilities in developing countries (Kim and Yi, 1997).

In line with Vernon's (1966) study that, as foreign investment established production facilities in a developing country, local labour participated in the operation of the plant, 'learning by doing' is most likely to be a major mechanism for increasing the efficiency of production, or productivity in the beginning stages of industrialisation (Bell, 1984). However, this kind of costless and unconscious learning is not likely to occur in technological learning through a national R&D programme.

These firm literatures argue that different technological learning mechanisms are required according to the technological progress of the organisation and industry (Bell, 1984; Hobday, 1997; Kim, 1999). However, it should also be noted that these mechanisms are also likely to vary according to the change of main actors, i.e. from firm technological activities to national R&D programme.

Pursuing long-term expectations and profits, i.e. the long-term viability of development of domestic technology and industry, the emphasis of the technological effort in national R&D is placed on developing indigenous TCs for the internalisation and self-reliance of the selected technology at national level. Furthermore, before an industry is formed, national R&D is likely to be a major actor in the development of the local industry.

Abernathy and Chakravarthy (1979) showed that government has actively participated in developing new technology (radical change) and improving conventional

technology (incremental change). Their findings showed that government has played an important role in technological change while directly investing in technology creation, intervening product characteristics and regulating market. Owing to this direct government intervention, they found that such science-based industries as computers, jet engines and semiconductors led to the expansion of the US economy after the 2nd World War (Abernathy and Chakravarthy, 1979).

In particular, direct investment from the US government in basic research and mission-oriented R&D, largely through national programmes, generated many of the most important technical breakthroughs from fundamental discovery to commercialisation. As these scientific and technological advances led technological activities of US companies, the national R&D led US global competitiveness and technological dominance during the post-war period until the end of 1970s (Mitchell, 1999).

More recently, Laia and Apen (1996) showed how national R&D, as a part of comprehensive national science and technology strategy, could be appropriately engaged in maintaining nation's industrial competitiveness in the global marketplace. From the perspective of sustainable development, they argued that US government direct investment through national laboratories need to provide the science and technology required by a domestic company to produce goods and services onshore and compete in the global marketplace. [4] This role of the national laboratory is particularly recommended in the circumstance where competitive advantage is not gained by individual companies (Laia and Apen, 1996).

In the science based and technology intensive industries, as shown in Abernathy and Chakravarthy's (1979) study, technological activities rely on organised R&D with scientific knowledge. Moreover, the technological activities of these industries carry a high investment risk with both high financial investment and low probability of returns in the short-term. On the other hand, complex science-based technologies, such as nuclear power and aircraft, have the large effect of horizontal utilisation over other disciplines and industries and vertical diffusion within the industry. In this way, technological change in such industries has a wide and long ranging effect on national

[4] They call this approach as 'sustainable competitive participation' (Laia and Apen, 1996).

S&T, industry and economy development (NEA/OECD, 1993; Lee *et al.*, 1998). Hence, national R&D is very likely to provide a technology seed for domestic industry while private firms are reluctant to invest in indigenous TCs building.

In sum, taking into account that learning by R&D in complex industries entails a long-run and substantial cost, national R&D is likely to be strategically carried out through direct investment by government for local industrial TCs building and/or national interests. Especially in developing countries with low TCs and high investment risk in terms of economics of TCs building, national R&D programmes could perform technological activities to cope with the demand of domestic TCs building while pursuing maximisation of the performance of international technology transfer. In viewing R&D as major part of technological learning process from the beginning, national R&D should be strategically linked to industrial needs while incubating and improving industrial competitiveness.

6. Conclusion

From the perspective of technological change in developing countries, this article concerns the relationship of the national R&D with Neo-Schumpeterian Technological learning. The endogenous course of technological change in developing countries cannot be explained by neo-classical economics and dependency theory (Fransman, 1984). Neo-Schumpeterian economics and technological learning approach are useful in the research which explores the dynamic mechanism of technological learning in developing countries as follows: Neo-Schumpeterian economics places more importance on incremental change than radical change while taking notice of tacitness of technology. Following the neo-Schumpterian perspective of technological change, the technological learning approach provides a theoretical base from which to explain the process of technological change within developing countries while stressing the reverse PLC (product life cycle) model through international technology diffusion and domestic technological effort.

However, the technological learning school has paid little attention to the role of national R&D in technological learning while considering R&D as the generation of new scientific knowledge and technology in global sense. In addition to Neo-

Schumpeterian technological change and technological learning, therefore, this requires an additional review of the nature and role of national R&D in TCs building undertaken largely by government research institutes in developing countries.

In understanding R&D broadly as a problem solving process in technological change, it can be considered from the beginning stage of the technological learning as well as the innovation stage. R&D is considered to play a role in not only searching out and selecting appropriate technology but also in absorbing and adapting this technology. In this way, learning by national R&D is likely to effectively exploit foreign technology to develop indigenous TCs as well as to generate innovation. Especially in the science based and technology intensive industries, the literature review showed that national R&D programmes are likely to lead to technological change in DCs while effectively exploiting foreign advanced technology to develop indigenous TCs, as well as to generate innovation.

Hence this article provides a theoretical alternative with which to investigate the empirical cases, the role of national R&D in technological change in developing countries (DCs). In accepting this, the contribution of national R&D from the beginning of technological learning could be appropriately examined in the study on technological change in developing countries.

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