The Failure of Sectoral Innovation System in Taiwan's Pharmaceutical Industry: the Misalignment of the Triple Helix?

Abstract

The study investigates Taiwan's sectoral system of innovation as it applies to its pharmaceutical industry, which has failed to achieve international competitiveness, despite strong state support. Our investigations were designed and carried out in two stages. In the first stage, we developed a statistical method to measure the institutional drivers in Taiwan's pharmaceutical industry. This finding received strong support in our second stage of analysis, which involved the use of both (1) inductive processes (through the use of interviews) and (2) deductive (i.e. mathematical) approaches to analyze the innovation performance in Taiwan's pharmaceutical industry. In particular, we compared patenting and publication activities in Taiwan with that found in India.

Taiwan has been listed in third place in the USPTO in terms of patents per capita, or in fourth place if measured by the total number of patents granted. However, despite the weaker performance in terms of sectoral innovative capability and quantitative patenting activity, the stronger qualitative innovation indicators (i.e. science linkage, current impact index, and length of technology cycle) exerted by Taiwan's pharmaceutical sector implies that the sector's endogenous innovation capability has already been built up. The innovation capability of Taiwan's pharmaceutical sector is shown not only in the fact that its public research institutes specialize in upstream research activity, such as molecular biology and microbiology

(the only technology area in which its performance is better than that of India), but also in the fact that the hospital excels in the midstream clinical trials of the commercialization process. However, the private sector does not present its significance in terms of the patenting activity neither of the publication activity. The interaction and network mechanism is one of the essential elements to prevent structural system failure in the transformative change (Weber and Rohracher, 2012). Our findings in Taiwan's pharmaceutical industry thus evidenced the importance of having a consistent structural mechanism in the sectoral system of innovation to bridge the misaligned linkages not only between the public and private sectors but also between upstream research activity and downstream development and market.

The results of our study demonstrate that the intellectual property regime (i.e. patents and publications) is playing as a critical role in linking actors and institutions and is highly associated with the effectiveness of innovation system in the pharmaceutical sector. While industrial success relies on the dynamics of the innovation system concerned, the results of this study also demonstrate that learning from the case of an ineffective innovation system is as important as understanding an efficient one in building a nation's innovation capability as a whole.

Keywords: innovation; intellectual property; pharmaceuticals; patents; Taiwan; India

1. Introduction

The promotion of the pharmaceutical industry is one of the main priorities of Taiwan's industrial policy, as demonstrated in a series of legislation, including the implementation of cGMP (Current Good Manufacturing Practices) and PIC/S GMP (the highest standard, as per the European GMP criterion). Nevertheless, despite a considerable degree of state support (even more than that awarded to the Information Technology area, in which Taiwan appears to be one of the critical leaders in the global market), our research question is why do the performances of Taiwan's pharmaceutical and Information Technology (IT hereafter) companies differ significantly in their patterns of innovation and competitiveness while both groups operate in a dynamic high-tech environment and share a common national system of innovation?

In line with the view of technological regime and institutional paradigm, Jung and Lee (2010) and Park and Lee (2006) contend that 'catch-up' in latecomer countries can only occur in certain sectors, whose technological life cycles are shorter and more explicit, and more easily embedded in importing mechanisms. The pharmaceutical sector can be characterized as having a tacit body of knowledge, along with a longer technological life cycle, but it is still characterized by a successful sectoral system of innovation in India. Although Castellacci (2007) suggests that sectoral differences may be attributed to varying levels of productivity, the diverse innovation performance within those countries engaged in 'catch-up' still poses a challenge to the themes of innovation systems.

There are different types of system failures, for example, infrastructural failure, institutional failure, network failure, capability failure (Edquist, 1997; Malerba, 1997;

Carlsson and Jacobsson, 1997; and Smith, 1997), and transition and transformation failures (Weber and Rohracher, 2012; and Jorgensen, 2012). Even though the terminologies and definitions of the systemic failures are various, these works acknowledge the importance of clarifying imperfection systems and the difficulty to distinguish the elements in one failure from the other. Moreover, the failure of some sectoral systems of innovation is linked with the success experienced by others, in that all the systems are mutually influenced. In this respect, the clarification of the elements for the failure of a sectoral system of innovation is essential if a nation is to build its innovation system as a whole. Using the framework of innovation system, this study identifies the misalignments of Taiwan's pharmaceutical innovation system as well as explores the role of intellectual property in this sector over the last three decades. Given the Indian pharmaceutical industry is a benchmark of emerging economies, we then extended the results of Taiwanese case to that of comparison with India .[1]

The remainder of the paper is organized as follows. In Section 2, the evolution of the sectoral system of innovation is addressed, along with the use of patent data to investigate the development of Taiwan's pharmaceutical industry. In Section 3, we introduce two interactive statistical methods, in order to clarify what drives Taiwan's pharmaceutical sector and the causal structure that is involved. In Section 4, the

[1] Due to the difficulty of data collection for India, this study is not able to make a comprehensive comparison for the sectoral systems of innovation between Taiwan and India.

empirical results for the sectoral system of innovation in Taiwan's pharmaceutical industry are analyzed. Then, we use six patent indicators and paper publication analysis to enable comparison of innovation performance with the benchmark Indian case in Section 5. The conclusions are given in Section 6.

2. Literature Review

National systems of innovation are important, but suffer from certain limitations in that a country may consist of many sectors both within its own territory and by virtue of cross-border interactions (Malerba, 2005). While a sectoral system of innovation should been seen as a broad, open, and flexible framework, the key characteristics of a sector, including its knowledge, its capabilities, its various types of actor, and its interactions and particular institutions, form the essential elements that can help to understand innovation activities in terms of their local, national, and global dimensions (Malerba and Mani, 2009). Indeed, the innovation process in a sector often across different geographical boundaries, especially in the catching-up countries, through deliberate intra-sectoral division of labour within and across a nation and the linkage with the global value chain. We therefore now discuss the complementary relationships that exist between national and sectoral systems of innovation.

2.1 National vs. Sectoral Systems of Innovation

It was Freeman (1987) who first proposed the concept of a national innovation system (NIS) in his study of Japan's technological development, defining it as the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies. Later studies employed similar definitions to build on this idea (Lundvall, 1992; Nelson, 1993; Patel and Pavitt, 1994). The concept of NIS is now widely accepted as making an important contribution to our understanding of the differences in innovation performance between nations. Although the concept of NIS is generally recognized as comprising a complex of functions and interactions between various actors and institutions (Liyanage, 1995; Smith, 1995; Hubner, 1996; OECD, 1999; Furman et al., 2002; Carlsson and Eliasson, 2003; Edquist and Hommen, 2008), it is bound by national boundaries and is difficult to examine quantitatively (Malerba and Mani, 2009).

As a complement to the NIS, the sectoral systems of innovation that take place across national borders aim to provide a fuller understanding of sectoral dynamics, in terms of (a) patterns of change and (b) the factors that affect the performance and competitiveness of firms/countries. Many authors have considered what drives the building of a sectoral system of innovation. For example, the descriptions of sectoral systems of innovation by Malerba (2004; 2005) suggest that knowledge regimes, market structures, and the degree of embodied technological change in the sectors are the major variables at the sectoral level; Link and Bauer (1989), Vonortas (1997), and Sigurdson (1998) suggest that the onward division of labour in the global pharmaceutical sector has resulted from the various types of firms who have tended to enter into innovation networks to pursue strategic or economic goals while Jorgensen (2012) demonstrates how different actors at all levels in the society navigate and perform strategic interventions to foster a sustainable system .

With respect to industrial interactions, international leaders in the global pharmaceutical industry generally pursue measures intended to yield economizing effect, which could include the sharing of the cost and risk involved in the highly uncertain development of a new drug. In contrast, small firms or technological latecomers generally have more strategic aims, which could include the creation of new business opportunities via the development or acquisition of technological capabilities, particularly in terms of the complementary technological resources achieved through institutional linkages. The aim in these cases is to increase the absorptive capacity of firms, thereby affording them the potential to gain access to a wider range of technological options (Cohen and Levinthal 1989). However, the degree of spillover from of these activities depends on the extent to which the development of sectoral systems of innovation is available to enable new opportunities to open up in markets and technologies (Dodgson et al., 2008; Malerba, 2005).

Castellacci (2007) further explains that sectoral differences in productivity are centered on five factors, namely appropriablity conditions, levels of technological opportunity, levels of education and skill, the degree of openness to foreign competition, and the size of the market. This has been seen in the innovation system of Japan, where the establishment of new industries (e.g. software) appears to be more difficult than in the US and Europe (Storz, 2008; OECD, 2006). Mani (2009) continues in the same vein by comparing innovation systems for India's pharmaceutical and telecommunication equipment industries. India's pharmaceutical industry is more innovative than its telecommunication equipment industry, but the latter has better market performance than the former. Mani suggests that the differences in market performance are in contrast to the efficiency of the structure of the respective sectoral systems of innovation.

Differences in sectoral systems of innovation, in developing countries in particular, stem from differences in learning behaviour and capability, which in turn are constrained by the technology, knowledge base, and institutional context (Malerba and Mani, 2009). Park and Lee (2006) conducted an econometric analysis of catch-up by industries in Korea and Taiwan, and showed that catch-up is more likely to occur in sectors with shorter technological cycles. Furthermore, Jung and Lee (2010) demonstrated that catch-up is more likely to occur in certain sectors than in others, depending on the degree to which technologies are more explicit and easily embodied in imported equipment.

The framework of the sectoral system of innovation is important, but relatively little work has been carried out in integrating and measuring its effect, either in terms of the diverse drivers involved, or in terms of the causes of failure. This study extends the work done previously by Furman, Porter and Stern (2002) in 17 OECD countries, and by Hu and Mathews (2005) for East Asian latecomer countries, and justified their national framework to the sectoral system for Taiwan's pharmaceutical industry. We attempt to adapt the work on national innovation systems and provide a longitudinal analysis in order to examine the sectoral innovative capacity of Taiwan's pharmaceutical industry. The main set of measures used will be detailed in the Methodology section.

2.2 Use of patent and publication statistics as indicators

Intellectual property rights include patent, copyright, trade secret, business methods, and etc. In particular, patents and scientific publication activities remain a central part of a nation's innovation system, forming an extremely important aspect that signals the health of the innovation process. One of the clearest indicators of innovation performance is the rate of take-up of patents issued by the US Patent and Trademarks Office (USPTO). Intellectual property rights are not a perfect proxy for innovation performance, but are nevertheless widely recognized as providing a reliable and unbiased indicator of the effort being expended on innovation by a country (Griliches 1990; Trajtenberg 1990).

The research-intensive pharmaceutical industry networks involve a variety of actors, such as (different types of) firms, universities, public and private research centres, financial institutions, regulatory authorities, and consumers over the value chain (PhRMA, 2008). There have been many failures and successes that have shown that the results of R&D derived from the complicated pharmaceutical value chain require regulatory protection, particularly in latecomer countries (Mansfield 1986; Moerman, 2006; and Simonetti et al., 2007). Patents are particularly crucial tools in the pharmaceutical sector for the reason that generic drugs are largely subject to reverse engineering in emerging countries as the basis of a learning process, despite of the problem of frivolous patents and business strategy related to patenting in pharmaceuticals which increase artificially the numbers of patent in the sector. However, by using patent data, Hagedoorn and Cloodt (2003) analyzed innovative performance, and found that the patent can serve as a representative indicator of innovative performance, particularly in high-tech industries.

On the other hand, in the long process of commercialization and science-oriented pharmaceutical sector, accessing and utilizing scientific knowledge is critical in the discovery and manufacturing process for both new drugs and generic drugs. The pharmaceutical sector is becoming increasingly aware that effective publications strategy is an excellent and cost-effective means to disseminate product messages to medical opinion leaders, to the broader medical community, to investors, and to the public as a whole. According to Cutting Edge Information (2008), 73% of pharmaceutical companies begin medical publications activities during the clinical trial phases in order to reinforce the opportunity for commercialization through the increase of awareness and recognition of medical stakeholders. Therefore, the patenting and publication activities in the innovation system of pharmaceutical sector are regarded as mutually reinforced and interacted strategies.

2.3 Taiwan's pharmaceutical industry

Taiwan's pharmaceutical industry is strongly orientated towards the domestic market, and dominated by large multinational companies (IMS Health, 2008), in contrast to the preponderance of SMEs in the wider economy. The production value of Taiwan's pharmaceutical industry was NT$125 billion (approximately US$41 billion) in 2011, which is only 0.5% of the global market. Taiwan's top 10 pharmaceutical companies in term of sales are all foreign multinationals except for Yung Shin is the only domestic company ranked at No. 10 ranked in the list (see Table 1).

Table 1 is about here

Although Taiwan's government has listed biotechnology (particularly biopharmaceuticals) as one of its national strategic foci since 2002, the total production value of Taiwan's pharmaceutical industry has not significantly increased since then. The value of the lower value-added bulk drugs has increased to NT$17.6 billion (approximately US$ 590 million), due to the expansion of Chinese market, while the value of the major higher value-added formulations (mostly generic drugs) has even declined from the value of NT$49 billion in 2003 to a mere NT$39 billion (approximately US$ 1.3 billion) in 2011, as shown in Figure 1. In the research-intensive pharmaceutical industry, Taiwan's stagnant performance may be partially derived from the lower R&D to sales ratio (averaging at 5% for public companies, with an industrial average of only 3.8% from 1999 to 2011), which compares rather poorly with the global industrial average of at least 10% (PhRMA, 2008). More interestingly, the total production value and export ratio of Taiwan's pharmaceutical industry have not been significantly increased in line with improvements in the quality of production activity, even though the implementation of the cGMP (Current Good Manufacturing Practices) regulations since 1995 has filtered out the unqualified companies and reduced the number of pharmaceutical companies from 237 in 1995 to 162 in 2008 (Department of Health, 2009).

Figure 1 is about here

The development of Taiwan's pharmaceutical industry over the last few decades can be divided into the four stages set out below.

(1) ***Home-based factory in the 1950s***: more than 600 companies were established, due to the regulated import of bulk drugs (Taiwan Food and Drug Bureau, 2009). These companies were all small-to-medium in size, with lower quality control, and operated primarily for the bulk packaging of drugs.

(2) ***Foreign technology acquired during the 1960s – 1970s***: since the 1960s, the establishment of foreign pharmaceutical companies, such as Takeda (Japan) and Pfizer (US), has helped to improve Taiwan's local pharmaceutical technologies

through foreign-owned (the US model) and joint ventures (the Japanese model) investments.

(3) ***Implementation of GMP regulations during the 1980s – mid 1990s:*** In 1982, Taiwan announced the implementation of the GMP regulations, which helps to reduce the number of pharmaceutical companies from 550 in 1982 to 237 in 1991, and successfully upgraded the industry as a whole. In 1991, the Taiwanese government took steps to satisfy patent law and the regulations of the World Trade Organisation (WTO) by introducing the BA/BE (Bioavailability/Bioequivalency) test standards for the generic production of drugs.

(4) ***Towards the international market during 1995 to 2007:*** Taiwan's domestically oriented pharmaceutical industry reached a critical turning point towards internationalisation in 1995, when the government implemented its National Health Insurance system, which greatly reduced the profit of the domestic markets, and enabled the emergence of the Contract Manufacturing Organisation (CMO), along with implementation of the cGMP criteria. With the aim of reaching more advanced markets, such as those of the OECD countries, the Taiwanese government announced the implementation of the much higher standard of the European GMP criterion (i.e. PIC/S GMP) in 2004. In 2002, Taiwan listed its biotechnology industry as one of its national strategic foci, with the prioritisation of the biopharmaceutical industry. Driven by the strength of public policy, two biopharmaceutical industrial clusters were established, namely the Hsinchu Biotechnology Park (with the top-tier Taiwan University Hospital at Hsinchu and the National Health Research Institute as research hubs), and the Nangang Biotechnology Science Park (with the top-tier Taiwan University Hospital at Taipei and Academia SINCIA as research hubs).

The formation of these industrial clusters was in line with much of the effort initiated by Taiwan's government, which included all the factors available under the sectoral system of innovation, such as the involvement of universities and public research institutes, financial incentives, legal regulations, the use of foreign technology, and access to international markets. This study thus aims to propose a framework of sectoral innovative capacity, in which a useful perspective for the evolving and (so far) relatively weak performance of Taiwan's pharmaceutical industry during the last few decades will be elaborated in greater details.

3. Methodology

In the study, we used two-stage interactive methods to clarify the cause and effect of Taiwan's evolving system of innovation in its pharmaceutical industry. In the first stage of our analysis, we applied the concept of the sectoral system of innovation to Taiwan's pharmaceutical industry during the years 1996-2007. The results were then validated by means of an interactive analysis in the second stage, which included the use of (1) inductive processes (interviews) using ten industrial and academic experts, and (2) deductive (mathematical) approaches to analyze the dominant workings of intellectual property regime on the innovation performance (1978-2007) of Taiwan's pharmaceutical companies, taking the performance of India as a benchmark and using biblimetric analysis as well as six quantitative and qualitative patenting indicators that were derived from a well-known consulting organization ipIQ (formerly CHI Research).[2]

3.1 Measuring Sectoral Systems of Innovation

[2] ipIQ (formerly CHI Research) is a leading Intellectual Property consulting firm that provides technology-oriented services, including IP-related industry surveys. It reports to firms that are contemplating the acquisition of other firms. The company has formulated various measures of patenting quality, which we use in our own calculations.

The thinking behind the present study derives mainly from endogenous growth theory, specifically the concept of the "knowledge production function" (Romer, 1990; Jones, 1995; Jones, 2002), in which the growth of new knowledge is correlated positively with the cumulative stock of knowledge and the degree to which human capital is engaged in R&D. The first stage of our analysis thus begins with the collection of data from the period 1996-2007, and focuses on what drives innovation in Taiwan's pharmaceutical industry. As suggested by considerable East Asian studies, critical public R&D expenditure in the sector is also taken into account. The three main sets of ideas that converge on the sectoral system of innovation are set out below.

(1) *Common innovation infrastructure*: the specific variables that apply to the pharmaceutical sector are Taiwan's population (POP), the value of the production in the pharmaceutical sector (INDUSTRIAL PRODUCTION), its approach to the protection of Intellectual Property Rights (IP), the number of full-time-equivalent scientists and engineers in the pharmaceutical related sector (FTE S&E), the total R&D expenditure in the sector (TOTAL R&D), and the critical public variable R&D expenditure in the sector (PUBLIC R&D).

(2) *Environment for innovation in industrial clusters*: the variables used in this case are the private R&D expenditure in the pharmaceutical sector (PRIVATE R&D), and the relative specialisation of the technological sectors related to the pharmaceutical industry (namely SPECIALISATION in pharmaceuticals) in the USPTO.

(3) *Linkages between innovative infrastructure and cluster-specific innovation*: in this case, the variables are the R&D expenditure of universities in areas related to the

pharmaceutical industry (UNIV R&D), and the availability of venture capital for the pharmaceutical sector (VENTURE CAPITAL).[3]

Apart from the patenting data (from the USPTO), all datasets were obtained from Taiwan's Science and Technology Statistics and the National Bureau of Statistics. The mathematical relationship to be estimated and analysed herein made use of a log-log formulation of the following kind:

$$L\,\grave{A}_{j,t} = \delta_{YEAR}\,YEAR_t + \delta_{country}\,C_j + \delta_{INF} L\,X_{j,t}^{INF} + \delta_{CLUS} L\,Y_{j,t}^{CLUS} + \delta_{LINK} L\,Z_{j,t}^{LINK} + \lambda\,L\,H^{A}_{j,t} + \varphi\,L\,A_{j,t} + \varepsilon_{j,t}$$

In this equation, L represents the logarithm, $\grave{A}$ the production of innovation, $YEAR_t$ the year-specific technology shock, C_j the sector-specific technology shock, H^A the R&D inputs in terms of human capital and financial resources, A the cumulative technological sophistication, X^{INF} the common innovation infrastructure, Y^{CLUS} the cluster-specific environment for innovation, Z^{LINK} the quality of the linkages formed between innovation infrastructure and the environment of cluster-specific innovation, and ε the sources of error.

The innovation ability of a sector depends heavily on previous investment, which is derived cyclically from the contribution of production output or value in the sector. Investment made during the early years of a company allows it to make better technological choices and to exploit new opportunities (Cohen and Levinthal, 1990). We therefore use industrial production and patent stock as dependent variables, because they reflect, respectively, the potential and actual capacity to support the accumulation of knowledge in Taiwan's pharmaceutical industry.

[3] The pharmaceutical related areas include pharmacy, chemical engineering, and chemistry.

These results were then verified and validated using (1) in-depth interviews with ten R&D or marketing managers in three of Taiwan's top five local pharmaceutical companies, as well as in the pharmaceutical public research institute (as shown in Table 2), and (2) the comparison of innovation performance between the pharmaceutical sectors of Taiwan and India.

Table 2 is about here

3.2 Innovation performance indicators

The comparative datasets between the pharmaceutical sectors of Taiwan and India cover patenting and academic paper publication that took place in the period 1978-2007, which is divided into three 10-year periods: 1978-1987, 1988-1997, and 1998-2007. The patent data was obtained from a computerized US patent database from the World Intellectual Property Search (WIPS) and academic published paper data was retrieved from the ISI database. Patents are the most valuable form of information available for competitive analysis, in which different indicators are used to predict the distinction of the value of innovations or competitiveness between the pharmaceutical industries of Taiwan and India. Even though papers are in the form of copyrights, they become public knowledge once published in intellectual property regime, which is often used as a mechanism for knowledge diffusion, and particularly used as a R&D commercialization strategy by catching-up latecomers in the pharmaceutical sector.

Data

Previous studies of this topic have used either the broader technology scope-oriented International Patent Classification (IPC) or the technology application-oriented US Patent Classification (UPC) as the unit of patent analysis for the pharmaceutical industry in different countries. For example, Lanjouw and Cockburn (2001) used two IPCs (A61K and A01N), and Simonetti et al (2007) applied USPC 514 and 424, to examine patenting activity in India's pharmaceutical industry. In order to obtain equivalent data sets for the pharmaceutical industries of the two countries, we firstly filtered all the patents granted to the top 10 global pharmaceutical companies in the USPTO, in which the top five IPCs and USPCs were found to take over 70-80% of the total number of patents granted (except for Johnson & Johnson, which takes only 40-50% due to the diversity of its business sectors), while the remainder of the IPCs and USPCs took a far smaller share, with less than 5% in each case.[4] The cross-checked top five 3-digit IPCs are A61K, C07D, C07C, C12N, and A01N, which correspond to USPC 514, 424, 435, 546, and 544, respectively. Given the broader technological nature of the scope-oriented International Patent Classification (IPC), we herein used the specific and application-oriented USPCs (the top five) as analysis units in this study (see Appendix 2).

The six innovation measures used in this study consist of three quantitative and three qualitative indicators for each time period. The quantitative indicators are the number of patents, the revealed technology advantage (RTA), and the technology concentration ratio. The qualitative indicators are the science linkage, the current

[4] The global top 10 players, in terms of global sales (2007) were Pfizer, GSK, Sanofi-Aventis, Novartis, Roche, AstraZe-neca, Johnson & Johnson, Merck & Co, Wyeth, and Eli Lilly. Please see Appendix 1 for the total share of the top five IPCs and USPCs taken by the top 10 players.

impact index (CII), and the length of the technological cycle. Due to the fact that patents can vary greatly in terms of their importance or value, the use of simple patent counts is unlikely to capture the full force of the innovative output of the sector (e.g. see Trajtenberg, 1990; Jaffe et al., 1993; Jaffe and Trajtenberg, 2002). The alternative is the patent qualitative measure, which is recognised as being a proxy that reflects the impact and depth of innovation activity. Many studies have established that patents that are frequently cited represent inventions that are economically and technically important (e.g. Griliches, 1990; Narin, 1993). The six patent indicators are described below.

Quantitative indictors:

(1) Number of patents. This is intended to provide a basic differentiation between the pharmaceutical industries of India and Taiwan.

(2) Technological concentrate ratio (or bias-adjusted Herfindahl-Hirschman Index (HHI)). This is a measure of the size of a specific technology in relation to the country as a whole. This represents the number of granted pharmaceutical patents divided by the total number of granted patents in a given country, which can act as an indicator of the importance of a specific technology in that country, and ranges from 0 (not important at all) to 1.0 (extremely important).

(3) Revealed technology advantage (RTA) – The revealed patent advantage is used to measure the share of the total number of patents in a sector (i.e. the pharmaceutical industry) for a given country, divided by the share of the world's total number of patents for that sector. We therefore herein consider that the RTA is able to represent

the relative technological efficiency and importance of a country in the global pharmaceutical industry.

Qualitative indictors:

(4) Science linkage. This is the number of patent references that cite papers from the scientific literature. Patents increasingly cite non-patent documents as prior art (i.e. where the patent knowledge based on), and many of these citations are papers in scientific journals. A high level of science linkage thereby indicates that a patent is building on a technology that is grounded in advances in science. This is particularly true in the research-intensive pharmaceutical industry.

(5) Current Impact Index (CII). This indicator represents the average number of times that patents from the preceding 5 years are cited in the current year in the USPTO, for a given sector, and indicates how frequently they were used as the foundation for other inventions.

(6) Technology Cycle Time (TCT). This indicates the speed of innovation or the rate at which the technology is turning over, and is defined as the median age of the patent cited on the front page of a patent document. The TCT is measured in years. This indicator can measure the pace of technological progress. Shorter cycles reflect faster substitutions, indicating a faster progress of technology, while longer cycles reflect slower substitutions, indicating slower progress (Narin, 1993).

Based on the top ten pharmaceutical companies in Taiwan and India respectively, we also examine their records for cutting-edge scientific knowledge as paper publication in the form of copyrights. Utilizing the ISI Web of Science database (including Science Citation Index Expanded, Current Chemical Reactions, and Index Chemicus), all the academic papers published in these indexes are retrieved and counted from 1978 to 2007.

4. Empirical results

4.1 Sectoral system of innovation

Table 3 shows the descriptive statistics used in the analysis that summarize the experience of the driving factors in innovation in Taiwan's pharmaceutical industry over the period 1996 to 2007. The annual innovative output PATENT is defined as the number of Utility patents granted to Taiwanese assignees by the USPTO. The main results are reported in Table 4, which shows the variance of patenting with respect to two measures of knowledge stock: the value of industrial production and the accumulated patent stock.

Table 3 is about here

Table 4 is about here

Table 4 shows the determinants of Taiwan's sectoral system of innovation in its pharmaceutical industry, by taking the value of industrial production and accumulated patent stock, respectively, as proxies for its knowledge stock. Given the importance of the potential size of the domestic market and intellectual property rights in the global pharmaceutical value chain, it is not surprising to find a significant positive contribution made by population (POP) and intellectual property rights protection (IP) to industrial production and to the innovation infrastructure in Taiwan's pharmaceutical sector. On the other hand, patent stock exerts a significant evolutionary impact (9.442) on the accumulated production of patents and on innovation base, while none of the other elements (including R&D manpower and public/private R&D) shows any significant contribution either to the creation of the innovation environment, or to the reinforcement of the building of innovation capability in Taiwan's pharmaceutical industry as a whole.

Using these empirical findings, our in-depth interviews with 10 industrial professionals and research experts in Taiwan further elaborate the weakness and the potential opportunity for building Taiwan's pharmaceutical sectoral innovation capability. These are set out below.

4.2 The insignificant drivers

The empirical results show that population size has made a critical contribution to the expansion of industrial production in Taiwan's pharmaceutical sector, a characteristic that stems from the availability of the domestic market and the development of clinical trials, such as those of the CMO. On the other hand, if we use the measure of patent stock to reflect the knowledge base, the accumulated patent knowledge becomes the sole significant driver for building Taiwan's innovative capacity in the pharmaceutical sector as a whole. An immediate question is then: why do other drivers do not show the same influence on the innovation system in Taiwan's pharmaceutical sector as they do on the IT or electronics sectors? As suggested by previous authors, we particularly emphasize the importance of using in-depth interviews to understand why the widely recognized essential innovation factors for the Asian latecomers, such as scientific and engineering manpower, public R&D support, private R&D expenditure, and industrial linkage, are not also crucial to the development of innovation capability in Taiwan's pharmaceutical industry. Two issues are concluded from the interviews and further verified our empirical findings, as what follows.

4.2.1 Crowd-out effect for Scientific and Engineering (S&E) Manpower

S&E manpower is widely seen as one of Taiwan's essential drivers in the 'economic miracle' of the development of high-tech industries (Amsden and Chu, 2003). S&E manpower (including bachelors and masters graduates, and doctoral researchers) in Taiwan's pharmaceutical sector increased from 567 in 2000 to 1274 in 2007. However, the recruitment of S&E manpower is still one of the major difficulties that face Taiwan's pharmaceutical industry, in which most pharmaceutical graduates prefer to work in hospitals or chemists' shops (due to the higher salary associated with the required pharmaceutical licenses), or failing that, to work in public research institutes (mostly working towards a PhD), while only considering the private sector as a fall-back option. As shown in Table 5, the manpower crowd-out effect is also seen in the pharmaceutical, chemical engineering and chemistry sectors, while the most talented graduates are attracted by Taiwan's prosperous Information Technology (IT) and semiconductor sectors.

Table 5 is about here

4.2.2 Misalignment between public and private R&D

R&D activity in Taiwan's pharmaceutical sector is mostly funded by the public sector, which increased its contribution from US$189 million in 2000 to US$311 million (17% of the total public R&D budget) in 2007. This figure is much higher than the benchmark for India's pharmaceutical sector, where its public R&D expenditure only accounted for US$116 million in 2007 (Union Budget and Economic Survey, 2008). In contrast, Taiwan's private R&D expenditure in the pharmaceutical sector was only US$ 77 million (approximately 4% of total industrial sales) in 2007, whereas in India the equivalent figure was US$500 million (approximately 7-8% of total industrial sales). The contrast in R&D investment between Taiwan's and India's public and private sectors is associated with their distinct market performance in the global pharmaceutical market, which raises an interesting concern regarding the role of government in the industrial development of latecomer countries.

The role of government in India's pharmaceutical industry has been widely acknowledged in adapting its local patenting system, along with India's evolving innovation capability in the private sector, while the aim in the public sector has been to link upstream research activity with downstream clinical and industrial collaboration (Charurvedi et al., 2007; Kale and Little, 2007). It is the intimate collaboration between the public and private sectors that has enabled India to become a critical actor in the global pharmaceutical market.

While the essential drivers for building a sectoral system of innovation in Taiwan's pharmaceutical sector are derived overwhelmingly from the protection of intellectual property, we then used the six patent indicators and biblimetric analysis described above to examine the variations in sectoral innovation performance between India's pharmaceutical sector (i.e. the benchmark) and Taiwan's, in order to explore some of the more insightful lessons gleaned from our empirical results, as described in the following section.

5. Sectoral innovation performance: Taiwan vs. India

As in Taiwan, 90% of India's pharmaceutical industry was dominated by foreign international companies during the 1970s and 1980s. However, its entrance into the WTO, along with the enforcement of international patent laws in 1995, was a milestone for India's pharmaceutical sector in its transition from being an imitator to becoming an innovator of processes (Chaudhuri, 2007; Kale and Little, 2007). The successful transition through the liberalization process and the end of some restrictions on manufacturing licensing on import and export since the mid-1990s has enabled India's local pharmaceutical firms to regain and take over 70% of the domestic market from foreign international companies in the 2000s. As shown in Figure 2, India's patenting rate was lower than that of Taiwan before the mid-1990s. However, a significant increase in pharmaceutical patenting activity since the 2000s has enabled India to overtake Taiwan in becoming one of the main actors in the global pharmaceutical industry.

Figure 2 is about here

By using the six USPCs identified here, Table 6 shows the comparison between the innovation indicators of the pharmaceutical sectors of Taiwan and India in the period 1978-2007 in each of the three decades concerned. It is clear that the pharmaceutical sectors of both India and Taiwan experienced similar low levels in the first two observed time periods (1978-1987 and 1988-1997). However, in the last decade (1998-2007), all the Indian innovation indicators (particularly the patenting rate, technological concentration rate, and RTA) led those of Taiwan. The importance of patenting activity in the pharmaceutical sector thus corresponds to the empirical results, as seen in Table 4, where the accumulated knowledge base (i.e. patent stock) and intellectual property protection are essential for building Taiwan's sectoral system of innovation. Taiwan's decreasing rate of technological concentration (less than 1%) and its RTA (0.14) can also explain its weaker performance in the global pharmaceutical industry, which implies that the pharmaceutical sector has not yet become a strategize and open innovation sector in Taiwan as a whole (Bianchi et al., 2011).

Table 6 is about here

In terms of patenting activity, India had a stronger innovation performance in its pharmaceutical sector than Taiwan, both in terms of its increasing rate of technological concentration (39.14%) and its higher RTA (5.36). This correlates rather well with India's successful transition in this sector, as well as constituting evidence of the importance of knowledge accumulation and diffusion within and across the evolutionary global pharmaceutical industry. We now turn to an examination of the agency of knowledge accumulation and diffusion in both Taiwan and India.

By examining the specialized areas in terms of USPC and innovation sector, Figures 3 and 4 (a) indicate that some 59% of Taiwan's pharmaceutical patents are owned by public research institutes (particularly USPC 435, which mostly refers to upstream R&D in molecular biology and microbiology), while 28% are owned by the private sector (particularly USPC 424, which mostly refers to downstream applications in bio-affecting and body-treating compositions). In comparison, Figures 3 and 4 (b) demonstrate that India's pharmaceutical patents are more equally distributed between public research institutes (57%) and industry (42%). The development of India's pharmaceutical technology is similar to that of Taiwan, where public research institutes are mostly specialized in upstream R&D activity (i.e. USPC 435), and the private industrial sector tends to focus on downstream clinical treatment drugs (i.e. USPC 514).

Figure 3 is about here

Figure 4(a) is about here

Figure 4(b) is about here

The accumulated knowledge in Taiwan's pharmaceutical sector is focused overwhelmingly on upstream research activity (i.e. USPC 435) with much less of a focus on downstream application development (i.e. USPC 514 and 424). This finding corresponds to the misalignment between innovation infrastructure and industrial performance, as demonstrated in our interviews and shown in Table 4. As demonstrated in Figure 4(b), India's public sector owns 57% of its total patenting activity, while the private sector owns 42%, indicating a rather stronger link between upstream R&D and downstream clinical trials in that case, and corresponds to the findings of Kale and Little (2007) and Simoetti et al. (2007). Their argument is further supported by comparisons between the top ten patent assignees in Taiwan and India (Table 7), in which only one private company (Yung Shin Co., which is also the only local company to be listed in Taiwan's top 10 companies by market share, as shown in Table 1) is ranked in Taiwan's top 10, compared with six private companies in the top 10 assignees in India.

Table 7 is about here

Figure 5 is about here

Figure 5 demonstrates the differences of publication activities in Taiwan and India. The publication activity by hospitals is focused on the exploration of midstream clinical trials in the pharmaceutical commercialization process and that of the pharmaceutical companies tend to use it as a marketing strategy to access the downstream market. It is seen that most of the publication activity in Taiwan is dominated by hospitals while the share of the top ten pharmaceutical companies is much smaller. In contrast, the private companies in India are seen to be more active on publication strategy than the hospitals. Correspond to the findings of the patenting activity above, the publication activity indicates that the Indian pharmaceutical industry is emphasized more on creating opportunity for commercialization in the market when Taiwanese pharmaceutical industry tends to put more efforts on discovery of scientific knowledge. Both patenting and publication activities are critical factors that drive the expansion of international pharmaceutical business (Cockburn and Henderson, 2003; Pradhan, 2007).

Taiwan has been listed in third place in the USPTO in terms of patents per capita, or in fourth place if measured by the total number of patents granted. However, despite the weaker performance in terms of sectoral innovative capability and quantitative patenting activity, the stronger qualitative innovation indicators (i.e. science linkage, current impact index, and length of technology cycle) exerted by Taiwan's pharmaceutical sector implies that the sector's endogenous innovation capability has already been built up. The innovation capability of Taiwan's pharmaceutical sector is shown not only in the fact that its public research institutes specialize in upstream research activity, such as molecular biology and microbiology (the only technology area in which its performance is better than that of India), but also in the fact that the hospital excels in the midstream clinical trials of the commercialization process. However, the private sector does not present its significance in terms of the patenting activity neither of the publication activity. The interaction and network mechanism is one of the essential elements to prevent structural system failure in the transformative change (Weber and Rohracher, 2012). Our findings in Taiwan's pharmaceutical industry thus evidenced the importance of having a consistent structural mechanism in the sectoral system of innovation to bridge the misaligned linkages not only between the public and private sectors but also between upstream research activity and downstream development and market.[5]

6. Conclusion

Given Taiwan's strong government promotion of its pharmaceutical/biomedical sector, our results explain Taiwan's weaker market performance in the research-driven pharmaceutical sector by identifying instances of specific misalignment between and

[5] Structural system failure is one type of the transformative changes, including infrastructural failure, institutional failure, interactions and networks failure, and capabilities failure. Please refer to Weber and Rohracher (2012) for the detailed discussion.

within its sectoral innovation infrastructure, its industrial clusters, and the linkages between upstream and downstream innovation processes.

Taiwan's research activity is mainly concentrated in the public research institute (e.g. the National Science Council and Academy of SINICA), while innovation capability in the private sector is under development (only one private company, Yun Shin, is listed in the top ten innovators and few publication activity toward commercialization is utilized). The under-developed innovation capability in Taiwan's private sector is derived not only from the conservative attitudes of family-run SMEs towards the development of the riskier new drugs and international market expansion, but is also exerted from the limited open innovation network and its industrial cluster.[6] Furthermore, Taiwan's national industrial policy has been focused on building endogenous technology capability, in order that any research outcomes generated by its public research institutes are required firstly to be diffused or licensed to local companies, rather than taking global market demand into consideration. The misalignment of innovation capability between the public and private sectors, along with conservative venture capitalism (most investment is in the lower-risk IT sector), thereby hinders the creation of innovation and intimate collaborations, resulting in a commercialization '*chasm*' in Taiwan's pharmaceutical value chain (Dodgson et al., 2008).

In connection with the influential role played by the state in encouraging technological latecomers, it is hardly surprising to see that in recent years, the Taiwanese government has made a great deal of effort to shift the misaligned or

[6] The limited open innovation network and cluster is one of the differences between the IT and pharmaceutical sectors (Dodgson et al., 2008). The pharmaceutical products are used to claim a specific market niche (e.g. a focus on a specific cancer), so that the membership of the innovation network and cluster is naturally limited, while IT products are inherently compatible and adhere to international standardization, thus open innovation is widely recognized and formed in the IT sector.

ineffective structural mechanism for Taiwan's pharmaceutical sector. The strong government support started with the implementation of the 'Biotechnology Industry Development Policy' in 2007, which focused mainly on R&D in new medicines or medication , with financial subsidy and the diffusion of research expertise from the public sector into the private sector. However, the sectoral innovation network is still limited until the 'Biotechnology Takeoff Package' was launched in 2009 with the aim to achieve an open innovation system in the bio-pharmaceutical sector through different organizational modes (i.e. licensing agreements, non-equity alliances and supply/provision of technical and scientific services) to enter into relationship with different types of partners (i.e. large pharmaceutical companies, product biotechfirms, platform biotech firms, and universities), as suggested by Bianchi et al. (2011). This package consists of four linkage approaches across the pharmaceutical value chain, namely (1) strengthening the industrial value chain linkage, particularly the pre-clinical development in the commercialization process; (2) establishing a biotechnology venture capital fund (expected to be raised jointly by the government and the private sector to the tune of NT$ 60 billion (about US$1.88 billion)); (3) promoting an integrated incubation mechanism; and (4) creating the Taiwan Food and Drug Administration (TFDA) to bring Taiwan's pharmaceutical related regulatory environment up to international standards. The aim of all these policies is to create the open system of innovation and bridge the internal and external gaps between and within the industrial value chain and the commercialization mechanism for Taiwan's pharmaceutical sector.

Although the restructuring of Taiwan's pharmaceutical sector is still evolving, this study provides an insightful perspective into the causes and effects of the ineffective sectoral system of innovation that characterizes Taiwan's pharmaceutical sector. The comparison with India's innovation performance shows the intellectual property regime (i.e. patents and publications) is playing as a critical role in linking actors and institutions and is highly associated with the effectiveness of innovation system in the pharmaceutical sector while the importance of a 'breakthrough technology threshold' for a technology latecomer in developing in a new business environment such as the pharmaceutical industry. While industrial success relies on the dynamics of the innovation system concerned, the results of our study demonstrate that learning from the case of an ineffective innovation system is as important as understanding an efficient one in building a nation's innovation capability as a whole. Furthermore, the involvement and direction of government intervention in shaping industrial development in latecomer countries is essential, and worthy of greater attention in order to investigate its impact on innovation structure and market performance, at least at the emerging stage, as in the case of India.

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Appendix 1: Top five IPCs/USPCs in the global top 10 pharmaceutical players, 2007

Company/Rank		1	2	3	4	5	Share of top five USPC/IPC
Pfizer	USPC	514 (48.61%)	424 (12.08%)	435 (4.84%)	546 (4.74%)	260 (3.94%)	74.21%
	IPC	A61k (52.71%)	C07D (20.58%)	C07C (4.99%)	A01N (4.37%)	C07H (1.85%)	84.50%
GSK	USPC	514 (35.14%)	424 (21.62%)	15 (10.81%)	536 (8.11%)	435 (8.11%)	83.78%
	IPC	A61k (54.05%)	C07D (10.81%)	A46B (8.11%)	C07H (8.11%)	C12P, B29C (5.41%)	86.49%
Sanofi-Aventis	USPC	514 (67.68%)	435 (8.54%)	544 (4.27%)	546 (4.27%)	530 (3.05%)	87.80%
	IPC	A61k (41.46%)	C07D (31.10%)	C07C (6.71%)	A01N (3.05%)	A61P, G01N (3.05%)	85.37%
Novartis	USPC	514 (32.78%)	424 (10.59%)	435 (10.43%)	800 (8.09%)	351 (3.42%)	65.30%
	IPC	A61k (31.94%)	C07D (10.51%)	A01N (7.26%)	A01H (6.76%)	C12N (6.59%)	63.05%
Roche	USPC	514 (23.94%)	435 (13.85%)	260 (9.92%)	424 (8.18%)	549、544 (3.96%)	63.81%
	IPC	A61k (26.55%)	C07D (23.46%)	C07C (10.62%)	G01N (6.38%)	C07H (3.93%)	70.94%
AstraZe-neca	USPC	514 (58.98%)	424 (6.19%)	546 (4.64%)	544 (4.33%)	128 (4.18%)	78.33%
	IPC	C07D (36.53%)	A61k (31.58%)	C07C (9.75%)	A61M (4.80%)	G01N (2.63%)	85.29%
Johnson & Johnson	USPC	128 (9.78%)	604 (8.68%)	424 (8.08%)	623 (7.49%)	351 (5.59%)	39.62%
	IPC	A61F (21.06%)	A61B (8.08%)	A61K (7.88%)	G01N (6.59%)	A61L (6.49%)	50.10%
Merck & Co	USPC	514 (39.13%)	424 (13.04%)	252 (9.32%)	435 (8.13%)	106 (2.86%)	72.48%
	IPC	A61k (46.05%)	C07D (14.95%)	C07C (6.90%)	C09K (5.46%)	A01N (2.69%)	76.05%
Wyeth	USPC	514 (61.56%)	435 (8.02%)	424 (6.99%)	546 (5.55%)	548 (2.88%)	84.99%
	IPC	C07D (45.63%)	A61k (28.06%)	C07C (5.45%)	C12N (4.32%)	C07K (3.29%)	86.74%
Eli Lilly	USPC	514 (43.62%)	435 (9.44%)	424 (9.38%)	540 (5.11%)	530 (4.92%)	72.48%
	IPC	A61k (44.61%)	C07D (25.02%)	C12N (4.86%)	A01N (4.43%)	C07C (4.27%)	83.19%

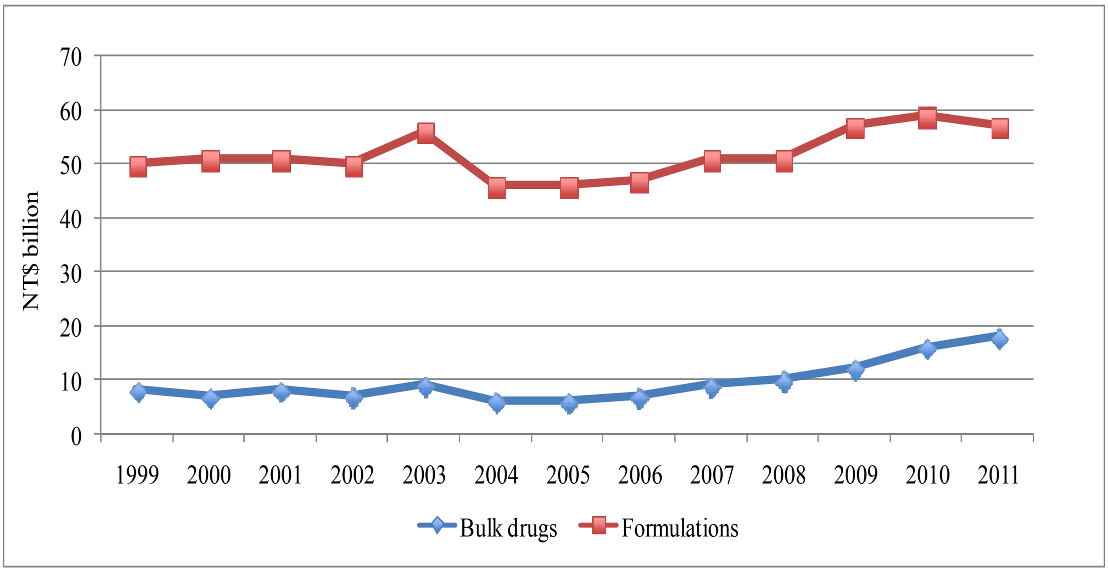
Source: USPTO

Appendix 2: Respective correspondence between and definitions of IPCs and USPCs

3-digit IPCs	Definitions	USPCs	Corresponding 5-digit IPCs to USPCs	Definitions
A61K	Preparations for medical, dental, or toilet purposes	514	A01N 47/00 A61K 31/26	Drug, bio-affecting and body treating compositions
C07D	Heterocyclic compounds	424	A61K 31/40 A01N 43/36	Drug, bio-affecting and body treating compositions
C07C	Acyclic or carbocyclic compounds	435	C11D 17/00 C11D 17/08	Chemistry: molecular biology and microbiology
C12N	Micro-organisms or enzymes; compositions thereof	546	A61K 31/235 A01N 37/10	Organic compounds -- part of the class 532-570 series
A01N	Preservation of bodies of humans or animals or plants or parts thereof; biocides, e.g. as disinfectants, as pesticides, as herbicides	544	A61K 31/22 A01N 37/02	Organic compounds -- part of the class 532-570 series

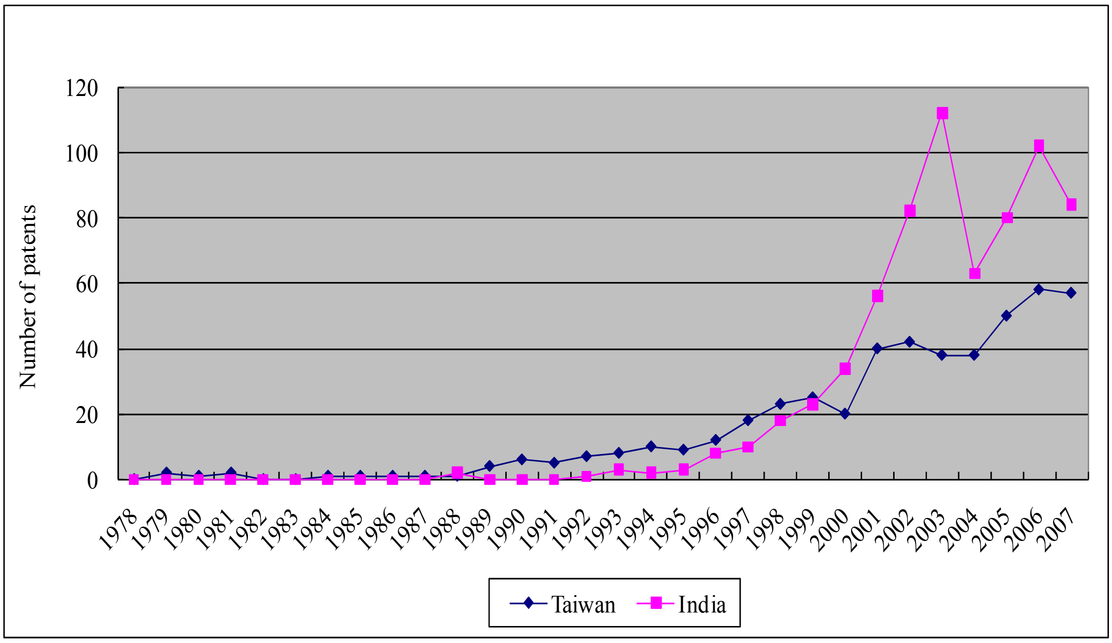
Source: EPO; USPTO; and WIPO

Figure 1: Production value of Taiwan’s pharmaceutical industry, 1999-2011



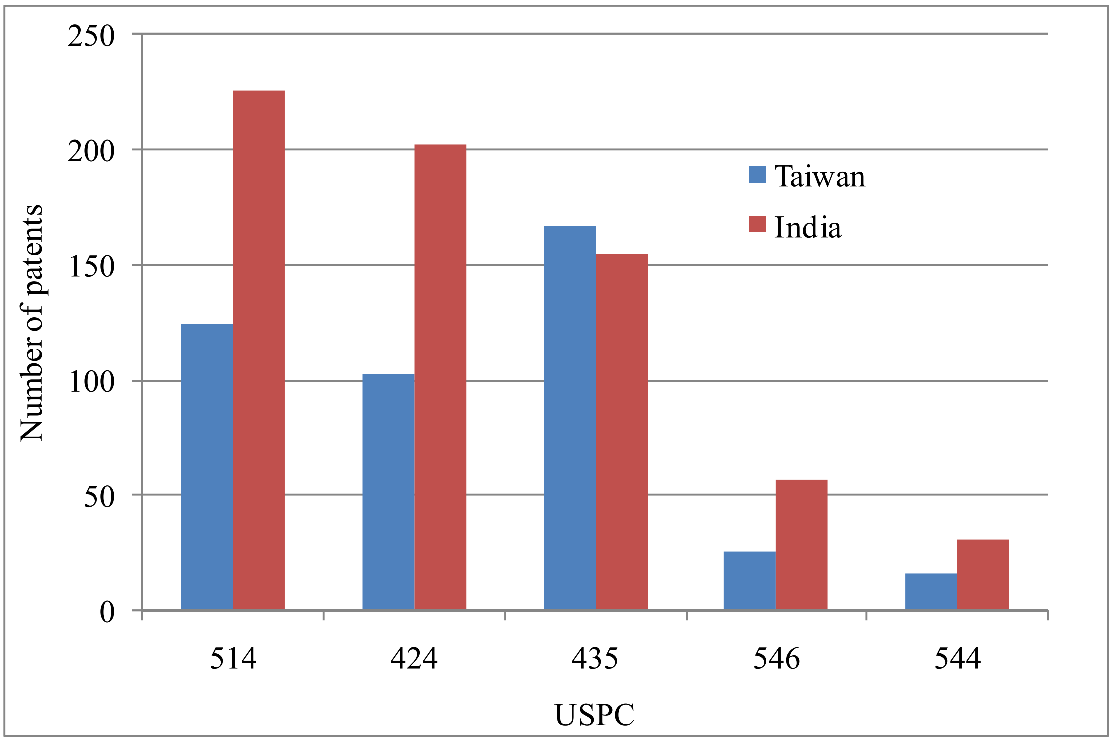
Source: IEK (2012)

Figure 2: Pharmaceutical patents granted in the USPTO, Taiwan vs. India, 1978-2007



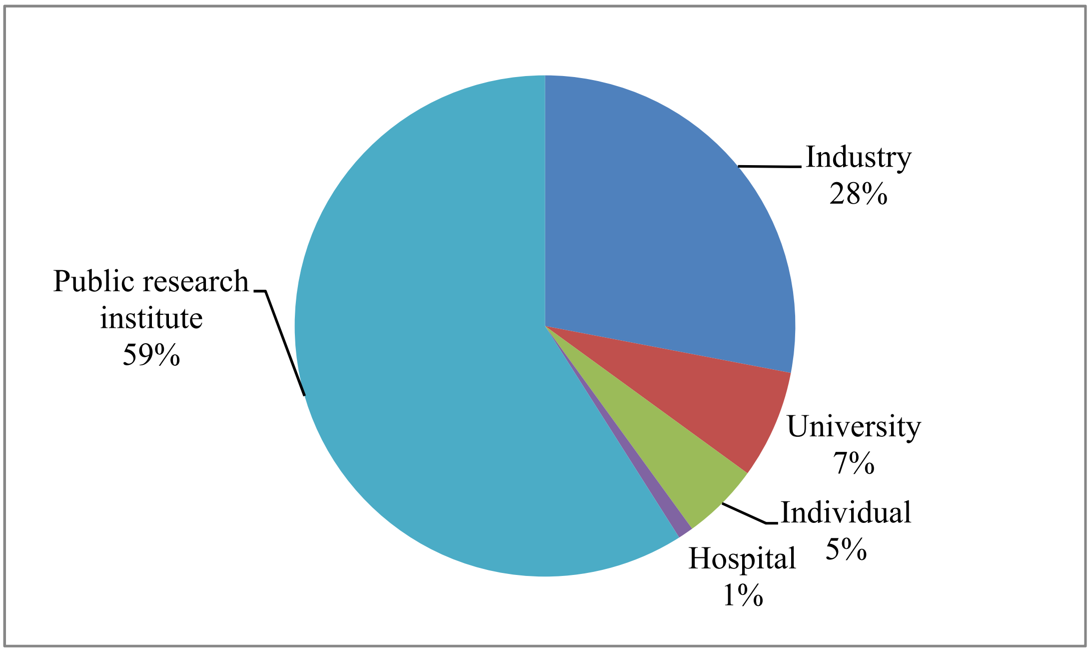
Source: USPTO search

Figure 3: Number of pharmaceutical related patents granted to Taiwan and India, by USPC, 1978 to 2007 (accumulated)



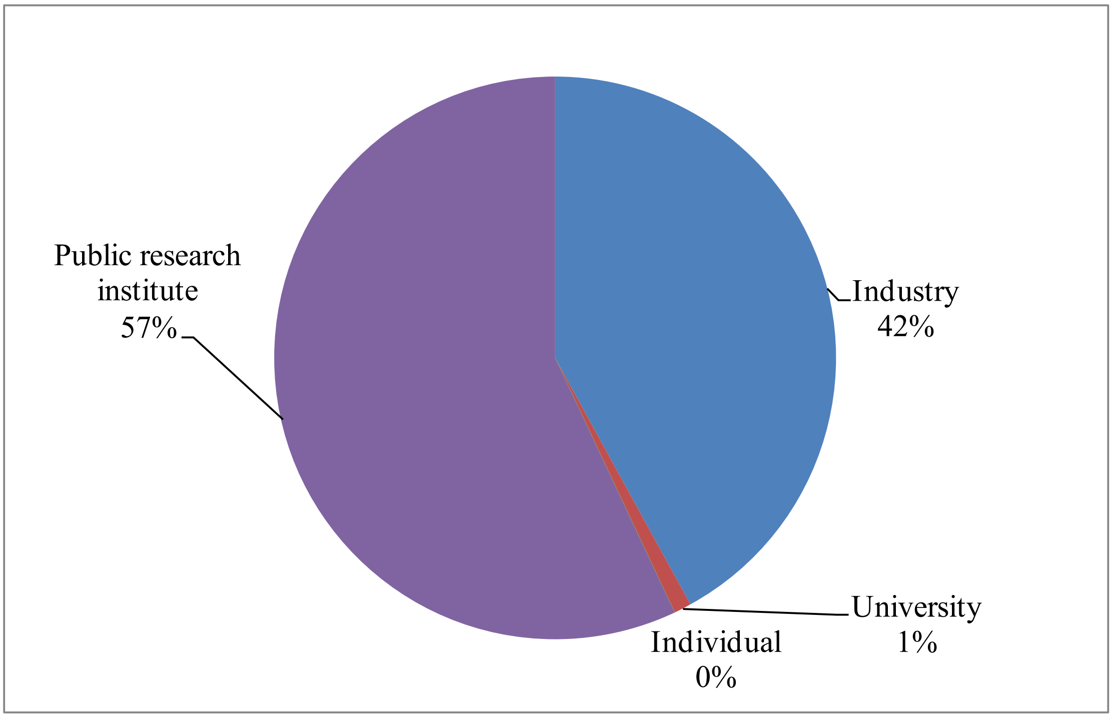
Source: USPTO and complied by the authors.

Figure 4 (a): Taiwan's pharmaceuticals assignee, by sector, 1978-2007



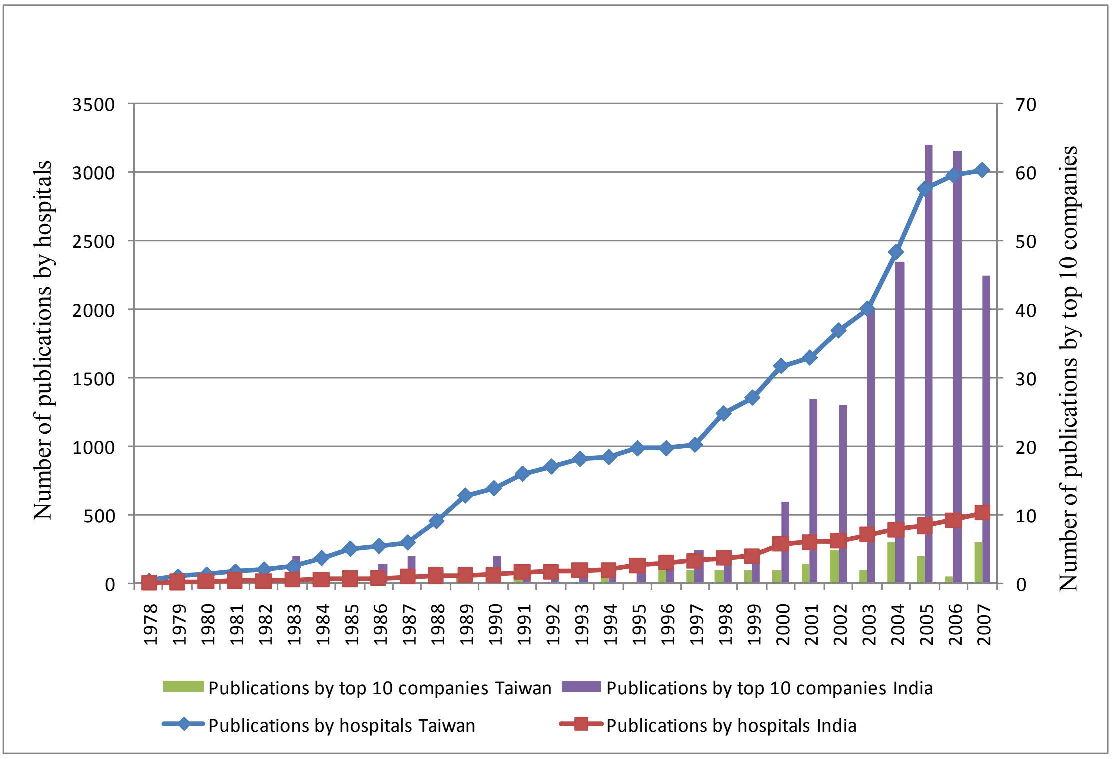
Source: USPTO and complied by the authors.

Figure 4 (b): India's pharmaceutical assignees, by sector, 1978-2007



Source: USPTO and complied by the authors.

Figure 5: Number of publications by companies and hospitals: Taiwan vs. India



Source: ISI database and complied by the authors.

Table 1: Top 10 pharmaceutical companies in Taiwan, by market share, 2007

Rank	Company	Origin country
1	Pfizer	USA
2	Sanofi-Aventis	France
3	GlaxoSmithKline	UK
4	Novartis*	Switzerland
5	Roche	Switzerland
6	AstraZeneca	UK
7	Merck Sharp & Dohme	USA
8	Bayer	Germany
9	Wyeth	USA
10	**Yung Shi**	**Taiwan**

Note *: Novartis is established by the integration between Ciba-Geigy and Sandoz (both are Swiss companies) in 1996.
Source: IMS Health (2008); IEK (2009).

Table 2: Descriptions of in-depth interviews

Companies	Positions	Times	Time Length
Yung-Shin Pharmaceutical Co.	(1) R&D manager (2) Marketing specialist	1	2hr 20 min
Standard Chemical & Pharmaceutical Co.	Vice President of Marketing Department	1	2 hr 10 min
China Chemical and Pharmaceutical Co.	(1) Marketing Manager (2) R&D engineer	1	1hr 45 min
Sun Ten Pharmaceutical Co.	Deputy Manager of Marketing Department	1	2hr 30 min
Scino Pharm Taiwan	(1) Vice President of R&D Department (2) R&D Manager	2	3 hr 45 min
Taiwan Advance Bio-Pharm Inc.	Senior Specialist, President Office	1	1hr 30 min
Biomedical Technology and Device Research Laboratories at Industrial Technology Research Institute (ITRI)	Project Manager	1	2 hr

Table 3: Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Patents	12	12	56	33.5	14.88
Patent stock	12	12.00	402.00	171.6667	128.77
POP	12	21.53	22.96	22.40	4.60
Industrial production	12	4.25	5.61	4.8707	0.353
FTE S&E	12	567	924	716	97.99
Public R&D	12	1.48	3.34	2.5613	0.523
IP	12	6.09	7.37	6.5673	.41919
EDU share	12	1.34	1.89	1.60	0.172
Specialization	12	.01	.21	.069	.00161
Private R&D	12	4.138	7.726	5.737	1.039
University R&D	12	7.94	23.5	14.928	5.08
Venture capital	10	0.03	1.64	0.53	0.045

Table 4: Industrial production/patent stock as knowledge stock

		Knowledge idea		Innovation infrastructure		Sectoral system of innovation: including all variables
		Industrial production	Patent stock	Industrial production	Patent stock	Patent stock
Common Innovation Infrastructure						
A	L patent stock		9.442***		3.469**	8.994**
A	L Industrial production	0.308**		0.349		
H^a	L FTE S&E	1.009	1.518	1.745	1.833	2.037
H^a	L POP	6.192***		2.639*		0.213
X^{INF}	EDU share			1.288	1.512	1.642
X^{INF}	Public R&D			0.525	0.605	-2.532
X^{INF}	IP			2.580*	2.115	-1.479
Cluster-specific innovation environment						
Y^{clus}	Private RD					-3.846
Y^{clus}	Specialization					1.274
Quality of linkages						
Z^{link}	University R&D					1.511
Z^{link}	VC					-3.653
Controls						
Year fixed effect		Significant	Significant	Insignificant	Insignificant	Significant
R^2		0.908	0.934	0.957	0.971	0.983
Adjusted R^2		0.873	0.907	0.907	0.920	0.996
N		36	24	72	60	120

Note: *P<0.1, ** P<0.05, ***P<0.01

Table 5: S&E manpower in Taiwan's pharmaceutical private sector, 2007

	PhD	Master	Bachelor	Technician	Others	Total
Pharmaceutical sector	159	635	480	176	43	1492
Chemical engineering and chemistry sectors	154	1009	1175	730	331	3399
Electronics and semiconductors sectors	1374	17360	14297	5248	1062	39341

Source: S&T Statistics (2008).

Table 6: Comparisons of innovation indicators between Taiwan and India, by time period

	Taiwan			India		
	1978-1987	1988-1997	1998-2007	1978-1987	1988-1997	1998-2007
Technological concentration rate	1.43%	1.34%	0.99%	10.34%	24.67%	39.14%
Revealed Technology Advantage (RTA)	0.25	0.19	0.14	1.8	3.18	5.36
Science linkage	1.75	7.53	7.19	1.33	8.61	7.85
Current Impact Index (CII)	2.75	6.71	3.81	2.56	9.39	4.34
Technology cycle time	7.8	7.6	3.8	6.8	6.4	3.1

Source: USPTO and calculated by the authors.

Table 7: The top 10 patent assignees of Taiwan's and India's pharmaceutical sectors in the USPTO, accumulated from 1978 to 2007

	Taiwan		India	
Rank	Top 10 assignees	Number of patents	Top 10 assignees	Number of patents
1	National Science Council	66	Council of Scientific and Industrial Research	344
2	Academy of SINICA	42	**Dr. Reddy's Laboratories Limited**	53
3	Industrial Technology Research Institute (ITRI)	39	**Ranbaxy Laboratories Limited**	38
4	Development Center of Biotechnology (DCB)	33	Dabur Research Foundation	24
5	Food Industry R&D Institute	31	**Panacea Biotec Limited**	14
6	**Yung-Shin Pharmaceutical Co.**	16	National Institute of Immunology	13
7	Medical and Pharmaceutical Industry Technology and Development Center	13	**Wockhardt Limited**	13
8	Council of Agriculture	10	Dr. Reddy's Research Foundation	10
9	National Health Research Institute	9	**Biocon India Limited**	10
10	National Taiwan University	5	**Torrent Pharmaceutical Ltd.**	9

Source: USPTO.