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In Search of an Innovative State: The Development of the Biopharmaceutical Industry in Taiwan, South Korea and China

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ABSTRACT

Recent developments in the biopharmaceutical industry in Taiwan, South Korea and China bear witness to the transformation of these states in nurturing an innovation-based industry. This article argues that the segmentation of the value chain of the biopharmaceutical industry has provided industrializing countries with a window of opportunity. These East Asian states have modified their former catching-up approaches by establishing a more effective institutional platform that can attract knowledge-creation players to the industry. Through case studies, the authors show that the Taiwan state's promotion of the biopharmaceutical industry has been based on an incremental approach; existing state policies have been modified to cope with the demands of the industry, which has resulted in the continuation of its SME-based industrial structure. The methods of the Korean state have been more radical, in that the policies that previously favoured the chaebols have gradually been reoriented toward the promotion of smaller, science-based firms that now co-exist alongside the chaebols. Finally, the Chinese state and local governments have sought to promote this innovation-based industry by building biotech parks. This approach has resulted in a boom in new science firms, which have become increasingly isolated from the flourishing domestic SOE-led market.

INTRODUCTION

As a representation of the knowledge-based economy, biotechnology has become one of the priorities that both developed and developing countries have been pursuing to advance their economic growth. Among the many different sectors within biotechnology, the biopharmaceutical industry is

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arguably one of the most important in terms of the value that it can generate.[1] For example, in 2005, the net profits earned by the ten biggest pharmaceutical firms (hereafter 'pharmas') ranged from US$ 3.6 billion to as much as US$ 10.4 billion. The most profitable pill, Lipitor, a cholesterol-lowering product of Pfizer, generated US$ 12.1 billion in revenue in 2005 alone (DCB, 2006: 181). It is hardly surprising that many countries dream of entering this arena in the hope of upgrading their economies.

In the past, the pharmaceutical companies used a vertically-integrated approach to developing new drugs that started with basic research and development (R&D), moved through pre-clinical and clinical tests, and extended to the marketing phase. Given that the whole process could take twelve to fifteen years and cost as much as US$ 800 million (Marcia, 2004), very few companies had the financial and technological capability to enter the new drug exploration game. As a result, the world market was dominated by a very small number of US and European firms. However, the molecular biology revolution beginning in the late 1970s has dramatically changed the process of developing new drugs (Comanor, 2007; Dosi and Mazzucato, 2006; Pisano, 2006).

The traditional method involved screening thousands of chemical compounds for efficacy against a given disease, and was referred to as the random drug design methodology. The molecular revolution in the 1970s changed this methodology into one of 'rational drug design', i.e., the development of more precise models to detect how the molecular structures of particular cells cause specific diseases and how they interact within the body (Comanor, 2007; Pisano, 2006). Since the early 1980s, biotechnological research techniques have been displacing traditional chemical methodologies, and large global pharmas have now integrated biotech into their drug development processes. In addition, as a result of institutional reforms that took place in the USA in the 1980s, the vertically-integrated process for developing new drugs has been broken up into different segments, allowing many parts of the process, including the expensive R&D segment, to be outsourced.[2] Approximately half of the 200 new drugs which were approved by the US Food and Drug Administration (FDA) between 1988 and 2000 were a result of this new type of collaborative process (Danzon et al*.,* 2005). It is against

1. Biopharmaceuticals generally refer to medical drugs developed by biotechnological methods, such as the use of proteins or DNA for therapeutic or diagnostic usage. This article defines the biopharmaceutical industry in relation to the value chain involving R&D processes for new drugs, from upstream discovery to downstream clinical trials.
2. Many laws were passed in the USA in the 1980s to encourage scientists and universities to collaborate more closely with private firms, including the Bayh-Dole Act (1980), the Stevenson-Wydler Technology Innovation Act (1982), and the National Competitiveness Technology Transfer Act (1989). As a consequence, many scientists have become scientist-entrepreneurs and have established new firms which focused solely on R&D and sold their research results to big pharmas prior to clinical tests (Dosi and Mazzucato, 2006; Pisano, 2006).

this backdrop that a number of countries, including Taiwan, South Korea and China, availed themselves of the opportunity to enter the biopharmaceutical industry in the hope of upgrading their economies.

The purpose of this article is to examine the processes through which these three countries have been developing their biopharmaceutical industries. In the past, the success of economic development in East Asia was mainly attributed by scholars to the efforts of developmental states to catch up economically with the advanced countries (Amsden, 1989; Evans, 1995; Wade, 1990; Weiss and Hobson, 1995; Woo-Cumings, 1999). This state-guided development has, however, encountered enormous challenges in seeking to establish new frontier and innovation-based industries. While it was relatively easy for the state in the earlier stages of economic development to learn from advanced countries, due to the availability of information, the very concept of frontier and innovation-based industries implies that the knowledge does not yet exist, and there is no clear model to learn from. The state's decision to develop such frontier technologies, especially those related to the biopharmaceutical industry, is thus a gamble.

We will argue, following an institutionalist perspective (Campbell, 2004; North, 1990), that because there is no clear blueprint to copy from, state bureaucrats in East Asia tend to follow or modify existing routes to construct their own development models. They digest, or even reconstruct, their past failed experiences and assimilate them with the experiences of the advanced countries. The state then adopts new strategies and builds new forms of institutions that are geared towards innovation-based industries, in which state bureaucrats collaborate closely with the scientific and financial communities to construct new infrastructure to support the new industries. That this form of state functioning may follow different patterns in different countries as a result of existing institutional arrangements is borne out by the fact that Taiwan, South Korea and China exhibit varied patterns of state transformation in the development of their biopharmaceutical industries.

THE STATE, INNOVATION AND INSTITUTIONAL COUPLING

In recent decades, the fragmentation of production — through which the branded global firms outsource most of their production functions to other parts of the world in order to lower their production costs — has become a dominant strategy in the business world. Firms rarely engage in the whole process of the value chain. In recent years this outsourcing trend has included R&D; branded firms avail themselves of the cheap workforces of industrializing countries to reduce their R&D costs (Ernst, 2005; Gereffi, 1994, 1999; Gereffi et al., 2005). A further implication of the outsourcing of R&D is that branded firms have been creating global innovation networks alongside the global production networks that have been established in the last few decades (Ernst, 2005; Ernst and Kim, 2002). In this way, firms in

industrializing countries have the opportunity to specialize in a particular set of activities and to upgrade their economies within the value chain (Ernst, 2005; Giuliani et al., 2005; Humphrey and Schmidt, 2002; Schmitz and Nadvi, 1999).

In the past, states in developing countries were expected to adopt a strategy of imitation and technology transfer from advanced countries to develop particular industries. The developmental state model has provided very strong explanatory support for late-industrializing countries in East Asia pursuing the process of economic catch-up (Amsden, 1989; Johnson, 1982). However, neither the Gershenkron top-down version nor the socially-embedded version of the developmental state model can adequately account for the transition of these economies towards building frontier innovation-based industries. This is because, as evidenced by Taiwan's semiconductor industry (Kim, 1997; Mathews and Cho, 2000) and Korea's telecommunications industry (Lee and Lim, 2001), the state's leading role was to set the goal and to form 'public–private collaborating networks' through which the state-sponsored R&D institutes were to transfer the knowledge learned to private firms, leading to growth in the industry. The state was the big brother in these public–private alliances.

This aspect of the developmental state model is based on two assumptions: first, that state bureaucrats have sufficient knowledge to adopt certain roadmaps that they have learned from advanced countries to transform the economy; and second, that the state is able to build global and local networks, construct infrastructure as well as induce private enterprises to invest in state-determined technology directions. While the model is convincing in terms of the state's role in facilitating the information and communication technologies (ICT) industry to catch-up, it does not shed much light on emerging issues such as how the state is able to nurture a frontier and innovation-oriented industry like biopharmaceuticals. To date, only a very few studies have dealt with this issue (e.g., Breznitz, 2007; Wong, 2004, 2005, 2011).[3] Due to the higher levels of uncertainty in biotechnology R&D, and the greater time lapse involved in turning ideas into products than in the case of the ICT industry, Wong (2004, 2005) argues that the state's role in developing the biotechnology industry has to be that of an enabler and supporter rather than that of a top-down leader. He particularly stresses the dimension of the state's adaptation to the features required for this industry, principally streamlining policies among state bureaucracies in order to achieve effective coordination; building R&D collaboration in fostering learning through interaction; and enhancing competition in strengthening innovation (Wong, 2004: 495). As Wong argues (2005: 187), the state has to be transformed so that it can construct 'a predictable and enforceable legal infrastructure more ideal for biotechnology innovation . . . The developmentally

3. The existing literature has mainly focused on labour-intensive industries such as shoes, garments and the hardware arm of the IT industry.

oriented state, by committing itself to providing supply-side inputs into the biotechnology sector, has taken on the role of *innovation enabler*'.

Similarly, Breznitz (2007: 29) maintains that in developing innovation-based industries, the state 'should concentrate on creating more broadly defined technological capabilities, and should focus on motivating private agents to work in these areas and to collaborate with one another and with the state'. Breznitz (ibid.) even argues that because of the fragmentation of production, there are multiple entry points which the state can pursue to form linkages with global networks. Therefore, the state can use its science and technology (S&T) policy to pursue innovation activities in individual segments of a particular industry, rather than for the industry as a whole. The state can be viewed as consisting of multiple chunks of bureaucracy, each with unique capabilities and embedded in society to pursue innovation within those segments (ibid.: 24).

Leading on from these views on the adaptation of the developmental state, this article further argues that as state bureaucrats do not have sufficient knowledge to lead and plan the new frontier and innovation-based industry, they will have to learn from their past experiences and from engaging in dialogue with scientists and potential investors in the market in order to facilitate the formation of this new biotech industry. We thus argue that the state should emphasize the creation of an innovation milieu through various S&T policies; moreover, state agencies should change so that they act as flexible facilitating agents, motivating potential private agents to participate, developing broadly-defined and open-ended collaborations that facilitate knowledge flows, and inducing the formation of multiplex networks from amongst existing R&D, financial and production networks. In this sense, the state can be described as an agent that facilitates innovation by establishing a platform on which the scattered knowledge-creators, such as researchers in universities and enterprises, can interact in order to generate new knowledge and new industries. In the end, multiplex networks are formed among domestic and international R&D, financial and production networks that are motivated by the state, but are not under its guidance or control (Breznitz, 2007: 29–31).

This kind of state role in facilitating the emergence of an innovation-based industry is similar to what Evans (1995) describes as the midwifery state function of the developmental state, in that it still emphasizes the importance of the state in building infrastructure for a new industry to emerge, and of the state's social embeddedness within society. However, our version of state adaptation in building and coordinating an innovation platform has fewer ingredients of state leadership in public–private networking, and places more emphasis on the importance of letting the market actors coordinate themselves. Thus, the state is still developmental in that it sets the development project as its policy priority and sets up a platform for interaction, but it then becomes a facilitator rather than an industrial leader. Key players coordinate their own activities via the platform, since state

bureaucrats do not have the necessary frontier knowledge. The state is facilitating, but not guiding, the formation of the market; since each actor has autonomy in determining whether or not to collaborate with others, the way that the market develops is beyond the state's control. Although the state function that we propose is similar to a neoliberal state policy in that it involves a very small degree of administrative guidance, it differs in that it stresses the state's policy priority in building a favourable environment for frontier innovation.

Last but not least, the transformation of the state's role does not occur in a vacuum, but always within country-specific contexts. In following the institutionalist perspective, we maintain that the new state role is an evolutionary product, whose institutional features have been embedded within and have also evolved from existing institutional arrangements. Even if there are some degrees of institutional change, many existing elements that have been inherited from the past are recombined and reconfigured. Institutional change, as Campbell (2004) argues, is a process of recombination, referred to as 'bricolage', in which existing institutions provide a tool kit or repertoire that actors are able to modify. In this sense, we can suggest that the state's transformation is not a process starting from scratch, but is rather one that tailors existing elements to blend with other ingredients to produce a new outcome.

The ability of a developmental state to adjust in order to facilitate the development of an innovation-based industry, in this case the biopharmaceutical industry, is largely affected by the specific institutional arrangements of that country. While each country will establish various types of platform mechanisms through which firms, R&D institutes and financial agencies can collaborate, the existing industrial structure in each case will largely shape the ways in which the new innovative industry is developed and the manner in which local firms are connected to the global value chain. Therefore, in contrast to Wong's (2011) argument on the convergence of political re-orientation among East Asian states in establishing their biotechnology industries,[4] we argue that, as a result of the divergent institutional arrangements of Taiwan, South Korea and China, each country exhibits different transformation paths and consequently diverse development outcomes in the biopharmaceutical industry, as will be demonstrated by the case studies.

4. Wong (2011) argues that, in their pursuit of biotechnology, the states of Taiwan, South Korea and Singapore have converged. Wong highlights two strategies: (1) 'Re-calibrate and manage expectations', in which the three countries all aim to re-set mid-term goals or re-define the scope of the industry so as to maintain the people's zeal for the newly-emerging industry; (2) 'Manufacture stars', in which states *produce* stars (scientists) as a showcase so as to sustain people's zeal for the industry over a period of time.

THREE COUNTRY CASE STUDIES

We have already seen that, while the segmentation of the biopharmaceutical industry value chain provides industrializing countries with a window of opportunity, the development of the industry in a specific country involves state policy in facilitating knowledge creation and learning as well as the institutional arrangements in which the firms are embedded. The following case studies show how these factors determine the different ways in which the biopharmaceutical industry has developed in Taiwan, Korea and China.

Taiwan: Incremental Adaptation of the State Function

The Successful ICT Route that Failed in Biotech

Taiwan's economic development has been based on a small- and medium-sized (SME) enterprise model (Fields, 1995; Wade, 1990; Weiss and Hobson, 1995). This is also evident in its pharmaceutical industry. In 2005, the average revenue of Taiwan's biopharmaceutical firms was only about NT$ 290 million (about US$ 8.8 million) and 59 per cent of the firms had annual revenue of less than NT$ 100 million (BISC, 2007: 76). The transformation of the value chain in the global biopharmaceutical industry provides the Taiwanese state with new leverage that can be used for economic upgrading.

Influenced by the global promotion of biotechnology, the Taiwanese state began to treat biotechnology as its pillar industry in the 1980s. In 1982, biotechnology was identified by the Executive Yuan's 1982 S&T Development Plan as one of eight key technologies that were integral to Taiwan's high-technology development programme. A new state-sponsored public R&D institute, the Development Centre for Biotechnology (DCB), was formed in 1984 with the mission of creating and disseminating knowledge to firms. One of the most significant activities undertaken by the state during this period was to set up two semi-state-owned firms, which were created by the DCB in collaboration with Sanofi Pasteur of France, with a view to accumulating knowledge related to the production of a vaccine for Hepatitis B and C. However, the project failed in the late 1980s when the two firms were unable to produce state-of-the-art products and it was finally terminated by the state in 1995.

The key reason for this failure was that state bureaucrats lacked the knowledge necessary to promote this newly-emerging industry. In establishing the DCB, the state aimed to copy the Industrial Technology Research Institute (ITRI) model which had been very successful in transferring knowledge to private firms in the IT industry, but no thought was given to the technological and timeframe differences between the IT and the biopharmaceutical sectors. Not only was it not easy to develop new drugs, but even when they had been developed, they still needed to undergo a long period of pre-testing

and clinical trials before they could be approved and commercialized. The consequence of this lack of knowledge was that the DCB was transformed into one of the R&D institutes engaging in basic scientific research,[5] rather than functioning as a mediating institute that could nurture and incubate new firms. In short, the Taiwan state's first foray into biopharmaceuticals tried to emulate its IT model by establishing an R&D institute and diffusing knowledge to private firms for production. As a result, very little was accomplished during this stage.

Incremental Transformation of the State

By learning from its earlier failures as well as from the successful experiences of the USA, the government modified its approach and once again promoted the development of biotechnology in 1995 (Wong, 2005). Based on the suggestions of domestic and overseas scientists,[6] a task force was formed which comprised government officials as well as academic and research-based organizations, to streamline the work of the diverse units: this was the Biotechnology and Pharmaceutical Industries Promotion Office (BPIPO). It was only then that Taiwan's biotechnological industry really took off in terms of new policy initiatives, scientific research and technology commercialization.

Since the implementation of the Biotech Action Plan in 1995, of which the establishment of BPIPO was a part, the state has also channelled more financial resources into the industry. The main strategies have been to subsidize firms' R&D expenses, provide tax incentives and low interest rates for lending, and induce venture capital to support the biotech industry. The level of state financial support increased from NT$ 6.7 billion in 1997 to NT$ 21.5 billion (approximately US$ 660 million) in 2006, or roughly a 3.2-fold increase (BPIPO, 2007: 117). Moreover, about NT$ 9 billion has been invested by venture capital firms into about twenty different new biotech firms (TVCA, 2007). In 2006, Taiwan's emerging biotech sector

5. In Taiwan, most of the public research institutions, such as the National Health Institute, ITRI, the DCB, and related university departments, receive funding mainly from the state and face fierce competition for national resources. Because developing new drugs is a time-consuming process, the DCB has to have academic research publications to show its performance in the meantime. Over time, the publication of academic papers has replaced the original *raison d'etre* of the DCB, which was to function as a mediating institute.
6. Including, for example, Dr Chi-Huey Wong who was an internationally prominent specialist in bio-organic and synthetic chemistry; he taught at Texas A&M University before he returned to Taiwan in 2000 and became President of Academia Sinica in 2006. Other examples include Dr Yung-chi Cheng, a prominent professor of pharmacology at Yale University; Daniel I.C. Wang, a pioneer in biochemical and biological engineering at MIT; Dr Cheng Wen Wu, a renowned specialist on virus oncology. He was a professor of cancer research at New York State University at Stony Brook before returning to Taiwan in 1988 to serve as the director of the Institute of Biomedical Science at Academica Sinica.

had 253 companies, with a total revenue of US$ 1.21 billion, of which many were created by overseas returnees from the US; and almost all of them were small- and medium-sized companies. Many of these newly-emerging biotech firms were established from the late 1990s onwards and were in the biopharmaceutical field.

The Taiwanese state also adopted two major policy measures to promote the industry. One was to provide a more comprehensive and appropriate legal structure, while the other was to set up a new type of financial support. Both have progressed at a slow and incremental pace. Firstly, with regard to the legal system, Taiwan's S&T Basic Law was introduced in 1999 to encourage technology transfer from R&D institutes and universities to private firms; however, it did not provide enough incentives to scientists to work with private firms or to create their own firms as compared to the US's Bayh-Dole Act (1980).[7] Scientists and researchers in R&D institutes or universities were only allowed to engage in profit-making businesses as consultants alongside their academic activities. Again taking the advice of domestic and overseas scientists,[8] a new law was enacted in 2007 — the Act for the Development of the Biotech and New Pharmaceuticals Industry. It aimed to encourage more scientists to create their own businesses as founders or shareholders, and to provide more financial incentives for them to transfer technology to private firms, following the spirit of the Bayh-Dole Act in the US (DCB, 2007).

Secondly, in order to channel more resources into the biotechnology sector, the state also changed the ways in which it provided financial support, from directly subsidizing the firms' R&D activities to distributing resources from the National Development Fund (NDF) to venture capital, and letting the venture capitalists decide on the investment. For example, under the 2009 Taiwan Biotech Take-off programme, the state has invested 40 per cent of the programme's NT$ 10 billion in the biotechnology venture capital industry, to be executed by a professional team. This suggests that privately-owned venture capital accounts for the remaining 60 per cent of the public–private joint stake (DCB, 2009). In short, the Taiwan state has begun to experiment with a new approach in fostering venture capital to work with

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7. The Bayh-Dole Act gives individuals the legal right to hold the patents and financial income generated from state-sponsored research. Although Taiwan's S&T Basic Law (1999) imitated the spirit of the Bayh-Dole Act, it did not allow individuals to hold the patents or the financial income generated by them: those belonged to the funding institutions. The scientists did not have the incentive (nor were they legally allowed) to create their own firms or to commercialize their R&D results to become commercialized patents. The Act for the Development of the Biotech and New Pharmaceuticals Industry in 2007 has largely eliminated these limitations.
8. This is further evidence that the Taiwanese state had little knowledge when it came to coordinating the activities of various agencies and to promoting the development of the biotech industry in an efficient way (Wong, 2005). It therefore turned to both domestic and overseas scientists and relied on their expertise.

R&D activities without controlling the decisions as to what should be done with the investment. In this sense, the state is creating a platform to generate possible collaboration for new knowledge.

Nurturing SMEs for Global Linkages

As noted above, the venture capital investment was concentrated in less than twenty domestic firms, most of which were founded by returnees or local scientists. For example, TaiGen Biotechnology was founded in 2001 by returnees and dedicated to new drug development, while TaiMed Biologics was also founded by returnees in 2007 and received a large amount of investment from the government that was dedicated to developing new drugs against AIDS (Chen, 2008). These newly-established science firms can utilize the R&D funding subsidized by the state, as well as the funding invested by venture capital firms, to engage in exploratory research that targets specific diseases. Once they achieve the desired laboratory results, either during or before the stage of the pre-clinical tests, they will sell the findings to big global pharmas in exchange for royalty fees, since there is no local firm in Taiwan that is big enough to conduct the clinical trials and bring the product to the global market (Tseng, 2008).

At the same time, local pharmaceutical companies are still producing low-priced generic drugs with little incentive or financial support from the state to engage in frontier drug discovery activities. The state concentrates its support on the newly-formed science firms, which have very little connection with domestic pharmas. Thus, most of the existing firms continue to produce generic drugs, while the few state-capitalized science firms have much closer linkages with global pharmas, and seem indeed to have become R&D centres for the global biopharmaceutical firms, with no local connections.[9]

South Korea: Radical Adaptation of the State Function

The Successful ICT Route that Failed in Biotech

The South Korean development model is well-known for its strong developmental state and its strategy of promoting national champions in the pursuit of economic growth. This model has been modified by the state following the 1998 financial crisis, with greater promotion of science-based SMEs. It is therefore interesting to investigate whether the Korean chaebol-dominated model still prevails in the biopharmaceutical industry.

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9. Interview with one of the Co-Chairmen of the Pharmaceutical Committee, European Chamber of Commerce in Taipei, February 2008.

Like Taiwan, the Korean state promoted the development of biotechnology as early as the 1980s, following the emergence of the new biotechnology sector in the advanced countries (Choi et al., 1999; Rhee, 2003; Seo, 2005). In the early 1980s, the Ministry of Science and Technology (MOST) included biotechnology as one of the state's strategic industries; in 1983, the Biotechnology Promotion Law was passed; in 1984, Seoul National University set up its Institute of Molecular Biology and Genetics with the ambitious goal of becoming one of the world leaders in basic and applied life sciences. In 1985, the Korea Research Institute of Bioscience and Biotechnology (KRIBB) was founded to engage in fundamental and frontier research; the hope was that the KRIBB, a public R&D institute, would follow the successful example of R&D in the IT sector, diffusing knowledge to private enterprises.[10] In the meantime, the Bio-industry Association of Korea was founded, partly supported by the government, to promote the development of biotechnology. In spite of this, Korea's biotechnology during this period was not very successful, largely because the state devoted most of its funding to the semi-conductor industry and because state bureaucrats lacked the necessary knowledge. In other words, the reasons for the failure of the top-down developmental state were similar to those in the Taiwanese case.

It was not until 1994 that the Korean state began to ambitiously promote its biotechnology industry once again by backing up its grand vision of the future with enormous financial input. This new promotion of the biotechnology industry was accompanied by the reformulation of the developmental state in the early 1990s as well as the collapse of the economy during the 1998 Asian financial crisis. Each had a great impact on Korea's development path. In the early 1990s, the Korean state began to implement a liberalization policy in order to support the chaebols' globalization strategy (Kong, 2000; Wang, 2007; Weiss, 1998, 2000). When President Kim Young-Sam came to power in 1993, he explicitly sought to end the government's provision of guidance which had been policy since the early 1960s. His abolition of the Economic Planning Board in 1994 indicated the end of the top-down developmental state approach in Korea.

Radical Transformation of the State

As the 1998 financial crisis broke in Korea, Kim Young-Sam's liberalization policy was blamed for its lack of structural and regulatory reforms (Kong, 2000; Wang, 2007). Therefore, when Kim Dae-Jung took control of the Korean government in 1998, he set a number of new policies in motion: on the one hand, he followed the direction provided by the IMF to restructure

10. This approach did not have the results that the government had expected: much like Taiwan's DCB, the KRIBB also became known for its academic output, and was not able to develop new drugs and transfer knowledge to local firms (interview with senior scientist at the Bio-Max Institute, Seoul National University, Korea, August 2009).

the economy, and on the other hand he deliberately introduced new laws to encourage and support the emergence of new science firms, as opposed to the former chaebol-dominated model. As a result of this new strategy, the function of the Korea Small and Medium Business Administration was expanded to cultivate a business environment that encourages start-ups with financial, technological, human capital and other assistance.

This transformation represented a diversification of the Korean developmental state's economic policy. The transition can also be observed in a number of legal measures. In the late 1990s, the Korean government adopted the Bayh-Dole Act (1980) to encourage professors in universities and researchers in R&D institutes to work closely with private firms. In 1998, it also passed the Law for Special Measures to Support Venture Business, which was openly intended to encourage venture capital to support SMEs engaging in newly-emerging innovation-based industries. Indeed, the Korean government began to institutionalize the KOSDAQ (a Korean version of NASDAQ) so as to enable small science firms to raise capital from the venture capital market. It also encouraged foreign direct investment as well as establishing R&D partnerships with foreign companies to gain resources for Korea's new science firms (Wong, 2004).

Along with these new financial tools and legal regulations, there were some specific policies that targeted the promotion of biotechnology, including the Biotech 2000 Programme in 1994, the 21st Century Frontier Research Programme in 2000, and the 2nd Framework Plan for the Promotion of Biotechnology (also referred to as Bio-Vision 2016) in 2006. To support its ambitious visions, the Korean government also increased its financial support for the development of biotechnology from US$ 53 million in 1994 to US$ 708 million in 2005, reflecting a 30 per cent annual growth rate in terms of R&D expenditure (KRIBB, 2008). This state funding has provided a range of incentives for biotechnology firms, including tax holidays, direct R&D subsidies and tariff reductions for firms acquiring foreign-produced equipment. The state funding has helped facilitate firms' R&D activities.

These transformations have led to the emergence of many new small science firms. According to a report of the Bio-industry Association of Korea, there were 605 biotech firms in 2006, of which 199 were focused mainly on R&D. This new trend has brought R&D institutes and private firms much closer together. Compared with its earlier attempts to promote biotechnology through the establishment of the public R&D institute, the KRIBB, which it was hoped would diffuse knowledge to private enterprises, the Korean state has transformed itself into a platform builder. Its aims are to create an innovation environment that facilitates links between R&D institutes and the private sector, to develop a venture capital market to support new scientific firms, and to radically reorient financial support mechanisms to encourage the emergence of scientific SMEs. As Wong (2004: 513) observes, 'faced with the challenges of generating first-order technology innovation,

the developmental state of today bears increasingly little resemblance to the dominant state model of years past'.

The Coexistence of SMEs and Chaebols

As the Korean top-down developmental state has been transformed into a platform builder, it has greatly changed the biotechnological landscape, especially that of the biopharmaceutical industry. On the one hand, the state's new strategies have not only encouraged the emergence of new small science firms as described above, but have also led many existing pharmaceutical firms to join the new science game. Like their Taiwanese counterparts, the pre-existing Korean pharmaceutical firms mainly produce generic drugs or traditional herb drugs. There were 553 firms of this kind in 2003. However, unlike their counterparts in Taiwan, the Korean pharmas were encouraged to enter the new drug discovery game. Among the existing domestic pharmas, some sixty to seventy firms upgraded their operations to develop new biopharmaceutical drugs, including Boryung, Dong-A, Green Gross, Chong Kun Dang and Daewoong (KDRA, 2006; Seo, 2005).

On the other hand, as the state encouraged its new biotechnology industry, many large chaebols also began to devote resources to developing new drugs. The LG Life Science group began its biotechnology venture as early as in 1981 when it set up a biotech research institute in the Daejeon science park. Another major group, the SK Group, ventured into the biotech area in 1987. Other chaebols such as Samsung, the CJ group, Daesan, Samyang and the TS group also invested huge amounts of funding in the biopharmaceutical industry. Samsung and the CJ Group committed around US$ 230 million per year to biotech for 2003 and 2004 — almost half of the total public spending for the development of biotechnology in Korea for 2004, which amounted to US$ 520 million (Seo, 2005). Such figures would have been inconceivable for counterpart firms in Taiwan and China. Due to the enormous financial input by these chaebols, the Korean biopharmaceutical industry has achieved some significant results in developing new drugs, and a few of them have already gained USFDA approval (KDRA, 2006).

Thus, the Korean state policy of promoting the biotech industry has had good results. The big firms have gradually become significant actors again in developing new drugs. In most cases, they have licensed the candidate drugs to US pharmas to apply for USFDA approval in order to penetrate the US market. For example, LG Life Science has formed an alliance with Genesoft, and SK has ties with Ortho-McNeil. The small science firms bear many similarities to those in the Taiwanese case, in that they conduct advanced R&D and then sell their products to the global pharmas, becoming R&D centres in the global value chain of the biopharmaceutical industry.

In sum, in the current Korean model, science-based SMEs coexist with chaebols. Despite the state's policy transformation and the financial support

to promote science-based SMEs, chaebols have gradually become significant players in the development of new drugs due to their enormous financial resources.

China: In Search of an Indigenous Innovation Model

The Chinese Development Model: The Local State's Economic Activism

Unlike either Taiwan or South Korea, China is a huge country with a big domestic market for the biopharmaceutical industry. The Chinese state established biotechnology as its pillar industry in 1986, through the '863' programme, hoping to rapidly catch up with the West (Webber, 2005). Over the past two decades, China has gone from simply importing technology and collaborating with multinational corporations, to now claiming to have established its own industrial technology through its indigenous innovation policy announced in 2006. As we will see, the biopharmaceutical industry is currently characterized by bifurcation between the emerging small science firms and the large state-owned pharmas.

The Chinese state is not a uniform entity, but is rather a collection of central and local states. By 1951, the Chinese system had already become multi-tiered and regionally-based, with much of the responsibility for planning, coordinating and industrial production devolved to local states. In the reform process, the local states were granted even more privileges and power in managing their local economic affairs. This resulted in the local states' economic activism, especially following the fiscal reforms in the 1990s which unleashed the political and material incentives for local officials to promote local economies (Oi, 1995; Segal, 2003; Shirk, 1993; Zweig, 2002).

The development of China's biotechnology industry is related to the reform of its S&T policy. The Chinese R&D system originated in the early 1950s, and was mainly transferred from the Soviet Union, in that it separated the R&D and production functions (White and Liu, 2002). The reform process has been trying to integrate these two areas. Among the S&T policies, the Torch Plan of 1988 has had long-term influence. After studying the success of the development of California's Silicon Valley, the Chinese government wanted to use the Torch Plan to promote high tech parks in China in order to create environments conducive to the development of high-tech industries by combining research with production activities. While the Torch Plan did not have as much funding as some other state-initiated projects, the Torch High-Technology Industry Development Centre of the Ministry of Science and Technology acted like a fundraiser and broker that collaborated with local states to provide the necessary infrastructure and preferential tax and financial incentives to support the development of high-tech enterprises (Segal, 2003).

Many science parks have now imitated the Californian example, building local innovation systems that integrate universities, R&D institutes and production units in order to generate synergy. Beijing's Zhongguancun is regarded as the Chinese version of Silicon Valley where elite universities, R&D institutes and firms are located (Segal, 2003; Wang and Leng, 2011). Other cities, such as Shanghai and Xi'an, have also adopted similar policy measures to enhance synergy and have persuaded high ranking universities to set up R&D centres in their science parks. Local states have also encouraged universities and R&D institutes to establish incubation centres to nurture new firms so as to diffuse their R&D results to the market. The state and local governments have promoted the use of venture capital to support the incubation centres and the newly-emerging science firms. They have also directly or indirectly subsidized enterprises' R&D activities, and used government procurement to support those enterprises that have indigenous technologies. These measures demonstrate that the Chinese states, at both central and local levels, have begun to adopt the strategy of platform building to stimulate knowledge creation and diffusion.

The Biotech Parks as Incubators for Small Science Firms

The Chinese central state began to promote biotechnology in its '863' programme (launched in March 1986). Subsequently, biotechnology was also included in various related programmes, such as the Torch Plan, and a series of five-year plans. Many so-called biotech parks or 'Medicine Valleys' were created in major cities such as Beijing, Shanghai and Tianjin. The major funding for developing biotechnology in China came from various state ministries, in which different agencies were responsible for their own targets. The total funding, however, was very small. The state devoted only RMB 179 million (about US$ 22 million) to biotech during the 1996–2000 period, with the amount co-invested by local states and SOEs totalling RMB 600 million (Liu and Wang, 2007: 135). Thus, although the state strategically promoted the development of biotech, public expenditure on R&D was very limited compared to Korea and Taiwan.

In order to speed up its technological upgrading, both the central and local states have made enthusiastic efforts to attract big global pharmaceutical companies to invest in their biotech parks. In recent years, they have seen some success: Pfizer and Novo Nordisk have set up R&D centres in Beijing, and Roche and Glaxo Smith Kline (GSK) have established laboratories in Shanghai. The reasons for setting up R&D centres in China are obvious: to take advantage of the low-waged scientists, and to prepare the way for a prosperous future in the Chinese market (BBNDPC, 2008: 46). As a local author observed, foreign firms rarely engage in advanced R&D in China, nor do they establish network connections with local firms. Rather, they have created only a low degree of knowledge diffusion, and have attracted the

best talents at the expense of local firms, due to the higher salaries that they can offer (Liu, 2008: 105).

On the other hand, new small science firms are growing rapidly, at a rate of more than 20 per cent per annum (BMI, 2010: 31). There are over 1,000 new science firms in China engaging in pre-clinical research, about 300 of them in Beijing and Shanghai. They have been established either by local scientists or by overseas returnees who had worked for foreign pharmas before returning to China. These are emerging R&D firms that have successfully integrated themselves into the value chain of the global biopharmaceutical industry and have become a new model in the Chinese pharmaceutical sector. For example, Pharmaron, Joinn Laboratories and particularly WuXi PharmaTech[11] (BBNDPC, 2008: 31–35) have become successful R&D centres for global pharmas such as Pfizer, Merck, Novartis and AstraZeneca Plc. The availability of low-waged scientists and experienced experts resulted in China being ranked the world's second largest bio-processing hub in 2003, after India (Finnegan and Pinto, 2006).

Besides the emerging science firms, there are many pharmaceutical firms that mainly produce generic drugs or traditional Chinese herb drugs. In 1998, the Chinese authorities implemented strict compulsory Good Manufacturing Product (GMP) guidelines to regulate the chaotic medicine market, and thousands of firms went out of business due to their inability to invest the estimated US$ 3–4 million to improve their production facilities. In 2004, the state again required that all drug manufacturers in China obtain GMP certification; this time, fewer than 3,000 survived (BMI, 2010: 14). Among these domestic pharmas, a few very large state-owned enterprises (SOEs) dominated the domestic market, such as Yangtze River Pharmaceutical and Shanghai Pharmaceutical. Some of these SOEs have become global active pharmaceutical ingredient (API) manufacturers and exporters, such as the Harbin Pharma Group and Northeast General Pharma. China has become the largest producer of API with a 25 per cent share of the global market (Wu, 2009). As Capie (2007: 104) observes, 'China remains a 98 per cent generic market with little new product development investment'.

The big Chinese pharmas are still playing an important role in supplying generic drugs for the domestic Medicare system, which has enabled them to take advantage of the booming market in producing generic drugs.[12] Thus,

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11. WuXi PharmaTech is already one of the biggest contract research organizations (CROs) in the world with a revenue of US$ 340 million in 2009. WuXi PharmaTech was created by a returnee from the US, Dr Li Ge. Before returning to China, Dr Li had already created a bio-firm in 1993, which was listed on the NASDAQ in 1998. In 2000, Dr Li returned to China to form a joint venture with a Chinese local firm to create WuXi PharmaTech. Since then, Wuxi PharmaTech has achieved significant success in the market and in 2010 was almost acquired by Charles River Lab at the price of US$ 1.6 billion.
12. According to IMS Health (DCB, 2010), the Chinese medicine market is going to become the third largest in the world, after the US and Japan. In 2009, its market value reached about US$ 30 billion. It was estimated that the Chinese medicine market had grown at a

these SOEs are more interested in becoming the branch agents of global pharmas or even becoming partners of these foreign firms. For example, the Harbin Pharma Group received investments from Warburg Pincus and CITIC Capital Markets amounting to US$ 200 million or a 22.5 per cent stake in 2004 (Capie, 2007: 101). The R&D expenditure of these big SOEs is on average less than 5 per cent of their revenue, which is far below the average of around 30–40 per cent for large international pharmas (Liu and Wang, 2007: 285).

A Dualistic Market

The economic activism of local states has resulted in a boom in new science firms in China. Nevertheless, the approach to funding of China's socialist institutional logic meant that resources were mainly channelled into public R&D institutes and universities (Liu, 2008). What the science firms gained in terms of financial support was mainly based on the provision of financial incentives and venture capital investment to attract them to locate in the biotech parks. They have gained little by way of R&D financial support from either central or local government.[13]

As a result, most of the new technology and knowledge in relation to biotechnology in China has been created by R&D institutes, universities and returnees from abroad (Liu, 2008). They have had little incentive to work with large domestic pharmas (Zhang et al., 2011), just as the latter have not been interested in investing in the new science firms, and have therefore become closely connected with foreign pharmas. At the same time, large domestic SOEs have little incentive to collaborate with the new science firms. Consequently, the Chinese biopharmaceutical market is characterized by a dualist phenomenon resulting from the different markets being targeted, with domestic-oriented, large-scale SOEs on the one side and foreign-oriented, high-R&D capacity, but small-scale science firms on the other.

The bifurcation of the Chinese pharmaceutical industry has been observed by the state, and has become the target of the 'indigenous innovation' strategy propagated by the central state in 2006. It has been announced that more than US$ 600 million will be spent on biotechnology R&D, and that by 2015 the state's support for local R&D is expected to top US$ 14 billion (BMI, 2010: 31). This strategy is an attempt to improve the current dualistic situation, but it will take some time for the state to understand and to resolve the institutional barriers that have created the bifurcation.

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rate of 17.6 per cent annually during 2000–2007 and that the growth rate would reach as much as 21 per cent annually in the period 2008–2013.

13. Interview with senior industry researcher in Shanghai, China, August 2009.

DISCUSSION AND CONCLUSION

This article has shown that Taiwan, South Korea and China have taken advantage of the transformation of the global biopharmaceutical industry to develop their respective industries. We argue that the states in these countries have adopted new policy measures to promote this sector, in which the states have become platform builders to advocate collaboration among universities, R&D institutes, venture capitalists and firms. We have shown that each of these countries has progressed very differently due to their institutional arrangements.

For Taiwan, the state's promotion of the biopharmaceutical industry has progressed very slowly and has resulted in the emergence of small science firms that have become more closely linked to the global pharmas than to the domestic firms. In South Korea, state policy has been transformed to encourage and support small science firms. Nevertheless, the majority of new drugs are still developed by a few chaebols, and are licensed to US pharmas in order to apply for FDA approval in the US. The Korean model has thus adopted a more diversified approach in which chaebols coexist with science-based SMEs. In China, the central state and local governments' promotion of biotechnology has focused on the building of biotech science parks which has led to the creation of many small science firms that are linked directly to global pharmas and isolated from domestic SOEs. The central state's recent indigenous innovation strategy is an attempt to rectify this bifurcation of the sector, but whether it will succeed remains to be seen. A comparison of these countries' chosen routes can be summarized as shown in Table 1.

The development of the biopharmaceutical industry in each of the three countries indicates that they are all pursuing industrial upgrading with a view to engaging in frontier innovation. All three states have developed ambitious policies and have transformed themselves into platform builders. Nevertheless, domestic institutional arrangements have constrained the capacity of the states, so that the three countries have exhibited different development paths and innovation patterns in developing their biopharmaceutical industries. Our case studies are of theoretical significance in at least three ways.

First, the state still plays a very important role in enabling an innovation-based industry to emerge in the advanced developing countries such as Taiwan and South Korea.[14] This new type of state function is different from

14. The same is true of some small Nordic states. For example, Finland is a small country with a weak biotechnology sector. The enormous success of Nokia led policy makers to think about establishing a new growth pillar alongside the IT industry (OCED, 2006). In the mid-1980s they chose biotechnology, especially biopharmaceuticals (Schienstock and Tulkki, 2003). The measures adopted by the Finnish state are very similar to those described here in the East Asian cases. First, the state has established many Centres of Expertise intended to offer business services to local companies, and to forge links between regional enterprises and local universities. Second, the state has started to invest heavily in

Table 1. Comparison of the Approaches of Taiwan, Korea and China

	Taiwan	Korea	China
Pattern of state adaptation	Incrementalism	Radicalism	Local states' activism
Legal system	Basic S&T law (1999); new biotech promotion law (2007)	Law for Special Measures to Support Venture Business (1998)	Based on Torch Plan (1988) and other S&T projects
Financial support	State support for R&D, National Development Fund, venture capital	State support for R&D, establishing KOSDAQ, venture capital	State support for R&D, but local states offering financial incentives to biotech Parks is important
National projects	Biotech Action Plan (1995); Taiwan Bioindustry Take-off Action Plan (2009)	Biotech 2000 (1994); 21st Century Frontier Research Programme (2000); 2nd Framework Plan for the Promotion of Biotechnology (2006)	863 Programme (1986); the Torch Plan (1988); series of Five-year Plans
Major promotion target	Small science firms	Both small science firms and chaebols	Small science firms
The transformation of the state's role	From network leader to platform builder	From picker of winners to platform builder	Local states as platform builders
Outcomes	Globally linked, but locally disconnected	Global linkage; chaebol may lead the industry	Globally linked, but locally disconnected

the networking or embedded state in which the state still exercises a leadership role. Now the state mainly creates an infrastructure and platform to induce firms, R&D institutes and the financial sector to work together. On occasion, the state invites giant global firms to invest in advanced R&D facilities in the local region in order to promote innovation. All these functions differ from the features of the former developmental state model where imitation and technological diffusion were the main mechanisms of economic catch-up.

A second, and paradoxical, finding of this study is that although Taiwan, Korea and China have developed their new biopharmaceutical industries, the firms that have emerged have nevertheless been incorporated into the value

biotech research projects as well as in education and research infrastructure to nurture the necessary human capital. Third, there has been massive state capital investment since the 1990s in biotechnology. Public financing plays an important role in Finnish venture capital markets in which very little investment comes from the private sector. Finally, most of the newly emerging science firms in the biotechnology industry are very small; they tend to engage in the R&D segment of the value chain and sell the products to the global pharmas (Brännback and Renko, 2002; Schienstock and Tulkki, 2003). All these features are very similar to those observed in the East Asian cases in which the state facilitates rather than guides the formation of the market.

chain controlled by big global pharmas. Indeed, while the state in each case has created a new science-based industry in its territory, this industry has not benefited the economy in terms of employment creation and the generation of profits for the society as a whole. Of the three case studies, only China seems to have the potential to escape from the control of global pharmas due to the massive scale of its market. In this way, it provides an interesting contrast with the cases of Taiwan and Korea, although this is an issue that will need further observation.

Finally, our comparative study shows that the development of a new science-based industry is co-determined by the state and the existing institutions. Although some authors have studied the role played by the state in facilitating innovation-based industries (e.g., Breznitz, Wong), they have paid little attention to the role played by society. Our comparative study has shown that the institutional arrangements within each country also influence the ways in which the biopharmaceutical industry develops. The state has created the platform, but the institutions shape the rules of the game. The states in East Asia are trying to reorient their economic miracle, but their success is not solely determined by themselves. History and institutions still matter!

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