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Managing the interface between public sector applied research and technological development in the Chinese enterprise sector

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Managing the Interface between Public Sector Applied Research and Technological Development in the Chinese Enterprise Sector

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Abstract

China's technological capabilities are emerging rapidly and the country will become a major challenger to established nations in terms of R&D and innovation in the near future. For the moment, however, contradictory signals emerge from the Chinese economy leaving experts pondering about the country's true potential for technological upgrading on a broad scale. The integration of the domestic research system, international technology transfer, and technological development remains limited to a few high-tech companies, while large segments of the domestic private sector have limited access to knowledge and technologies to upgrade their activities.

It is the core argument of this paper that technological development in China is not suffering from a lack of innovative capacity or human resources, but from a mismatch of research supply and demand. It is suggested that the expansion of successful domestic knowledge generation beyond a limited number of highly publicised S&T 'mega projects' depends on an improved management system for the interface between public applied research and technological development. The empirical analysis brings together data on the Chinese innovation system with evidence from the electronics industry in Guangdong province.

Keywords: China, Guangdong, interface, knowledge supply, knowledge demand, regional innovation system, science-industry relations

1 Introduction

According to many recent accounts, China is emerging as a player on the world stage of research and technological development. It has become difficult to survey academic literature on East Asia without encountering case studies concerning either upgrading and learning in China's domestic industries, or R&D investment by foreign multinational corporations (MNCs) (Li/Yue 2005).

Nonetheless, for the time being, these activities remain but an iceberg floating in a sea of less innovative activities which are driving the nation's impressive overall economic growth. Nearly all academic studies conclude that, as of today, much of Chinese industry continues to depend on international technology transfer.

In order to improve this, from a policy point of view, less than satisfactory situation, the Chinese leadership has embarked on an ambitious project, the 15-year medium- to long-term plan for science & technology with the proclaimed aim to reduce reliance on foreign technology to a mere 30% by 2020 (Cao et al. 2006; OECD 2007; Whalley/Zhou 2007).

Additionally, however, this long-term planning simultaneously envisages strengthening China's capacities in basic research, which are considered insufficiently developed as they receive a mere 5% of national expenditure on R&D. This, however, leaves room to question how China will proceed to achieve success in simultaneously accomplishing these very different tasks, even given that substantial resources can and will be mobilised.

A reduction of the reliance on foreign technology would require a boost in domestic research, not only in the industrial, but also in the public research sector. The task would be to develop and adequately manage a supply of technology that would be vital to Chinese enterprises in their upgrading process. This aim, however, is highly inconsistent with the notion of a shift towards basic research.

Arguably, as of today, the Chinese innovation system is characterised by fragmentation and a technological and organisational mismatch between its main domestic players. Other than in technologically leading nations, domestic enterprises do not turn to domestic institutes for technology transfer to an extent sufficient to provide a basis for the future national technological independence envisaged by the government.

In the following, we will argue that a domestic nexus of technological cooperation and knowledge exchange does not evolve automatically. We emphasise the fact that the successful exchange of technology ultimately develops along the lines of supply and demand. For a country like China, dependence on international sourcing might make

perfect economic sense and will only be altered if an attractive domestic substitute becomes available. Even if national policies can implement R&D interactions, they cannot 'order' the exchange of technological substance where there is no match available.

It is from this starting point that this paper sets out to elaborate on the underlying dynamic of knowledge exchange and to inquire into the nature of technology supply and demand in the Chinese innovation system. Particularly, we will investigate micro-level data to understand the current nature of technology-related industrial activities in one of China's most dynamic regions.

Ultimately, we will attempt to make suggestions as to how the interface management can be improved so that China will be able to simultaneously push for advances in basic research and accommodate the needs of its upgrading industries on a broader scale.

2 Conceptual considerations on technology supply and demand in developing countries

2.1 Technology transfer interfaces in innovation systems

In recent years, the innovation system approach has become a commonly used tool for the analysis of a country's technological capability under all sorts of different circumstances. Nevertheless, or even precisely for that reason, we believe that it is helpful to reiterate some of the main tenets of this approach, before we start analysing particular issues in a country with characteristics as specific as China's.

Most basically, an innovation system is about actors, the networks connecting them and the framework conditions allowing them to do so (Edquist 1997; Leydesdorff 2004; Lundvall 1988; Nelson 1993). A large body of work has been devoted to the role that different actors play within the system, recurrently focusing on the changing and evolving role of university, public research institutions and innovative business (cf. e.g. Edquist 1997). Recently, the contingency and instability in the interaction between them has been characterised as a "triple-helix of university industry-government relations" (Etzkowitz/Leydesdorff 1997; Etzkowitz/Leydesdorff 2000).

Actors in an innovation system generate, transform, administer and distribute knowledge. To do so, they have to interact. To realise this interaction, in the sense of Powell (1990), actors can be described as facing the choice between market and hierarchy. In practice, however, there is a continuum of quite a number of different

possibilities, most of which do to some extent depend on market forces, while on the other hand they are to some extent enabled by administrative action, be it through legislation or the establishment of knowledge market intermediaries (more commonly known as technology transfer agencies). Beyond knowledge generation itself, the establishment of markets for innovation is thus one of the key tasks that need to be performed in an innovation system (Cooke/Leydesdorff 2004: 9).

The appropriate scope of such an approach – national, regional, sectoral or technological – has been subject to much debate (Breschi/Malerba 1997; Carlsson/Stankiewicz 1995; Cooke 2004; Cooke et al. 2004; Leydesdorff 2004; Revilla Diez 2002). Despite its importance it will not be the main focus of this paper. Doubtless, actors and framework conditions indeed tend to be territorially rooted at different and overlapping spatial as well as industrial levels (cf. e.g. Bunnell/Coe 2001). Despite all its contingency on technology and knowledge, the degree to which innovative activity is policy-driven or at least policy-contingent should not be underestimated (Koschatzky 2001; Kuhlmann/Arnold 2001).

On the other hand, however, we agree with another common main line of reasoning that no innovation system approach can meaningfully be based on the assumption that innovative networks were contained within the boundaries of either a sector or a territorial entity. On the contrary, most of them are trans- or at least international in nature (cf. e.g. Bunnell/Coe 2001).

Instead, we would like to draw attention to a main issue, which in our view is indispensable for the understanding of innovative activities in emerging countries: the interface between knowledge and technology production and demand. Ultimately, innovative linkages are driven by the supply and the demand for knowledge. "Innovations are generated [...] in interaction with market forces. The two dimensions are traded off at interfaces: what can be produced in terms of technical characteristics versus what can be diffused into relevant markets" (Leydesdorff 2006: 15). The existing interfaces for technology transfer are thus contingent on technology supply and technology demand (technological development), as well as on framework conditions, and consequently change in the course of time (Leydesdorff 2006). Where there is no match between supply and demand, there will be few incentives for interaction, undermining the *conditio sine qua non* for innovative networking. Rather than being systemic by nature, therefore, many regions and even countries we tend to approach as innovation systems may in fact be characterised by fragmentation and insulation.

The main point here is that the often quoted domestically anchored co-evolution of actors in an innovation system (cf. e.g. Kuhlmann/Arnold 2001) will happen only if the

interfaces of technology transfer are anchored nationally and are thus able to tie together the actors in question. Networks among domestic actors are contingent on domestic technology supply and demand. Evidence compellingly demonstrates that actors do not necessarily form any innovative linkages even when located in geographical proximity. If market forces are allowed to play freely, knowledge supply and knowledge demand may thus be very well matched internationally rather than locally, as the following paragraphs will illustrate. A domestic nexus of technology interfaces is a possibility rather than an automatic, predetermined outcome.

The joint characteristic of these interfaces in most technologically leading economies is that they are of a complex nature, including multiple actors (Etzkowitz/Leydesdorff 1997). In hardly any of these countries, however, is the supply of technology for the industrial sector restricted to the industrial sector alone (while of course there are defence-oriented, non-public sub-systems in countries such as the U.S. and the U.K., for which this is the case). For the public research sector, in contrast, multiple configurations exist, contingent on the overall set-up of an economy (ERAWATCH ; TrendChart). Again, however, it is rare that applied research efforts in the public sector do not play a defining role. Notable exceptions from this rule are, for example, the Scandinavian countries, where R&D expenditure remains concentrated in universities and enterprises (ERAWATCH ; TrendChart). It is worth pointing out, however, that these are small countries dominated by a few large enterprises. To our knowledge, there is no technologically leading country with an innovative enterprise sector diversified by firm size and technological level in which public applied research does not constitute a defining element of the triple helix.

2.2 Upgrading and knowledge demand in developing countries

Companies in developing countries are articulating a rising demand for new knowledge and technologies during the process of industrialisation, since input-driven growth is necessarily subject to diminishing returns (Krugman 1994: 64). The required efficiency growth – or total factor productivity – is not just derived from 'new to the world' technological innovation, but could also be reached by shifting resources to high-productivity uses or improved technical efficiency, by catching-up with international best practice (Davies 1996: 685). All of these upgrading activities require knowledge inputs that may be new to the region or to the firm and they thus qualify as an innovation, according to the OECD definition (OECD 2005).

A look at the firm level in the Asian newly industrialising countries (NICs) shows that these companies may gain their competitiveness from cost advantages during a first

phase of the industrialisation process. However, the more intensive use of the factor labour results in higher prices of this factor, and the cost advantage is subsequently hollowed out by new competitors in even cheaper locations. Firms could respond with three generic strategies to these threats (Porter 1980: 39): (i) overall cost leadership, (ii) differentiation, (iii) focus on certain markets or products. Each strategy is closely connected with certain innovation activities, i.e. product, process, organisational, and marketing innovation (OECD 2005). Cost competitiveness is derived from improved efficiency of existing production processes or more responsive organisational models. Differentiation is reached by the introduction of new products, and focusing needs marketing innovation to approach the focus group of customers in the specific market. Internally, firms need specific competences to implement these strategies and to reach a sustained competitive advantage (Barney 1991). The development of these dynamic competences constantly requires inputs of new knowledge and technology (Teece/Pisano 1994) and an open-system approach towards interaction with partners (Madhok 2002).

Besides this general observation, two related theoretical considerations are of special interest for the aim of this paper to assess the efficiency of the interface between public research and technological development in China: (i) What kind of knowledge are firms in developing countries sourcing externally from developed countries or from local sources, what can be generated by these firms themselves? (ii) If external inputs are required, what are the pros and cons of international knowledge transfer versus domestic knowledge generation?

2.3 What kind of external knowledge demand is required and for what kind of upgrading?

Innovation in developing countries is defined broadly as all efforts to search and improve a firm's capabilities and it is understood by Lall (1992: 166) as a continuous process of absorbing and creating knowledge which is determined by external inputs and the accumulation of skills and knowledge in the past. The processes of innovation and learning are interactive in their nature and thus require cooperation among different partners (Dosi 1988; Kline/Rosenberg 1986; Lundvall 1992). On the one hand, firms have to develop internal capabilities to assess, acquire, understand, implement, and use new technologies (Lall 2000: 16-21). On the other hand, a firm's external environment contributes to its internal capability formation. Internal capability formation will not be discussed in depth, since this paper is focussed on interfaces with the external environment. To capitalise on external knowledge sources, firms need linkage capabilities, i.e. 'skills needed to transmit information, skills and technology to, and

receive them from, component or raw material suppliers, subcontractors, consultants, service firms, and technology institutions' (Lall 1992: 168). Linkage capabilities at the firm level also have a positive impact on economic development as a whole, by diffusing knowledge throughout the economy.

There is substantial evidence for the relevance of external knowledge sources in developed and developing countries in the literature mentioned above, but the analysis of the actual needs have to take into account the specificities of institutional backgrounds, sectoral scope, firm characteristics, and upgrading strategies. First, the configuration of university-industry-government linkages in transition economies like China or eastern Europe differs from that in established market economies (Etzkowitz/Leydesdorff 2000; Inzelt 2004). The emergence of the triple helix in transition economies is largely concerned with the empowerment of universities and companies to act autonomously from the still dominant state bureaucracy. Second, high-tech industries like biotechnology might be much more closely related to the scientific base than medium- to low-tech sectors which dominate in developing countries. However, it should not be overlooked that there is ample and often neglected potential for innovation in these sectors, both in developing countries whose companies have to catch up with international best practice, but also at the technological front in developed countries (von Tunzelmann/Acha 2005). These companies might not have a demand for latest scientific research results, but for applied industrial research and development consultancy to implement basic improvements in their production processes. Third, knowledge transfer within multinational firms differs markedly from domestic firms and more specifically SMEs which may struggle with very basic problems, like the accessibility to knowledge. In the latter case, firm boundaries represent an additional institutional barrier besides regional boundaries. Absorptive capacities and thus the ability to search for suitable knowledge are expected to be lower for firms in developing countries.

Fourth, at the level of individual firms, the upgrading strategy might have an influence on knowledge demand. A firm can either upgrade its products, production processes, or value chain position (Hobday 1995). The former two strategies are in general initiated by imitation and reverse engineering. In this case, the role of domestic knowledge generators has to concentrate on providing customised solutions to improve product or process innovation capacities, e.g. to enable the production of products that are at an earlier stage of their life cycle, the design of products, or the application of new processes. The so-called 'reverse life cycle' model was largely followed by large Korean *chaebols* (Wong 1999). In contrast, the process of upgrading within the value chain is characterised by increased competences in product design and branding. At first, original equipment manufacturers (OEM) receive all product specifications from

their customers. But successful OEMs have the chance to bargain for a greater degree of freedom with their customers if they have proven their ability to master the production process efficiently and advance to original design manufacturing (ODM) with own competencies in the design of products and processes. Finally, firms can focus on the development of own brands and invest in marketing and generic product development on the basis of their manufacturing experience and become original brand manufacturers (OBM). The value chain model was most prominent in the Taiwanese electronics industry (Hobday 1995). Another upgrading strategy that is directed towards the domestic market and may thus be relevant for Chinese enterprises is application pioneering, i.e. picking up a new trend and quickly applying it to a certain market. In the final stage of the catching-up process, more and more companies will succeed as product or process pioneers as companies from the first generation NICs like Korea, Taiwan, and Singapore have shown (Wong 1999). Their technological needs will then be quite similar to those of firms in developed countries since they are competing at the technological frontier right from the beginning.

In China, several models of upgrading co-exist, due to the size of the economy and the history of different locations. For example, the Bohai region is dominated by state-owned heavy industries and large national research facilities, as well as R&D laboratories of foreign MNCs (Hennemann 2006; Sun/Wen 2007; von Zedtwitz 2004; Zeng et al. 2006); foreign-funded enterprises in diverse industries as well as the research facilities are heavily concentrated in the Shanghai region (Chen 2006; Sun/Wen 2007; Zeng et al. 2006). In our case study of the province Guangdong, satellite factories of companies from Hong Kong and Taiwan in light industries account for a large portion of the industrial activity (FHKI 2007; Lu/Wei 2007). The knowledge demand is expected to differ markedly among these companies. The Bohai model might be suitable for close linkages to the scientific base, while Shanghai might be dominated by knowledge transfers within multinational companies and knowledge diffusion via their linkages to local suppliers. Instead, the Guangdong model is dominated by SMEs in the electronics sector embedded within global subcontracting networks of their parent companies. Thus, upgrading within the value chain as applied by Taiwanese companies is expected to be applied by a large portion of manufacturers in Guangdong. Recently, domestic companies and the domestic market are gaining relevance in Guangdong. The influences of ownership and market orientation on upgrading strategies and knowledge demands will be analysed below. The design of intermediaries has to take this diversity into account to provide relevant supplies and interfaces for the actual demand of knowledge.

2.4 Domestic knowledge generation and international technology transfer

In the initial phase of learning processes in developing countries, imported technology is the most important external source. Later, when a country has reached more advanced stages of technological development, however, international technology transfer can and should no longer serve as a substitute for domestic knowledge generation (Lall 2000: 20). Nonetheless, it remains a crucial complementary effort to keep up with changes in international markets. The advantages of acquiring technologies from developed countries are self-evident: they already exist when needed and quality and practical utility have been proven in the international market. Such technology, however, becomes less and less readily available as the technological capability of an economy develops: multinational corporations, fearing competition, become loath to share information, particularly when IPRs are less clearly defined. Additionally, the prices for machines or licenses in international markets can be prohibitive. Especially domestic SMEs in developing countries may therefore not possess the financial resources to set up production lines at the technological edge.

The most fundamental challenge to efficient local capability formation by means of international technology transfer is therefore related to the absorptive capacity of domestic firms (Ernst/Kim 2002). Cohen and Levinthal (1990: 128) defined absorptive capacity as the ability of a firm to recognise the value of new, external information, assimilate it, and apply it to commercial ends. Most studies on absorptive capacities in developing countries are focused on the firm level, i.e. internal capabilities of firms to absorb external knowledge from international sources. The role of other domestic sources of knowledge generation, e.g. universities, public research institutes, industrial research associations, is thus marginalised in the literature. Liefner and Schiller (2008: 281) discussed the extended role of universities in the process of technological upgrading. They introduced the concept of academic capabilities to cover the set of functional skills and organisational ability of a country's higher education institutions to carry out this role. The academic capability framework can also be applied to the wider context of domestic knowledge generation by the above mentioned non-firm actors. They also have to streamline their capabilities according to the technological needs of the private sector if they want to contribute efficiently to the overall upgrading efforts. Recommendations for action at the end of this paper will especially contribute to this point for the Chinese context.

Public support for local knowledge producers may help to overcome market failures for long-term investment in innovation and learning and thus accelerate and guide the upgrading process. Companies in developing countries which face even higher entry

barriers for innovation activities might otherwise stagnate at a low level of technological capabilities for a long time, if their external environment does not support the upgrading process. In this process, domestic research providers might have a kind of 'antenna function' (for universities discussed in Revilla Diez 2002) since they are able to absorb latest scientific knowledge via their international networks and transform it into applicable technologies that are appropriate for local technological needs. An explicit policy to link public research with the upgrading process also increases the efficiency of public spending in this field. But universities alone are not a sufficient source of all kinds of technological services. Due to their focus on basic, and to a certain degree, applied research, certain parts of their activities are necessarily incompatible with firms' needs for support in experimental development and other issues without scientific content.

Finally, each innovation system is characterised by typical forms of interaction and thus typical set-ups of markets for technology and innovation (Etzkowitz/Leydesdorff 1997; Leydesdorff 2004). As in any market, failures can occur, even in the presence of ample supply and sufficient demand. It is quite evident, particularly with a view to transitional economies, that interaction can be obstructed or even precluded by obstructive framework conditions or government action. Less evident, but in our view no less important, is the lack of knowledge about opportunities to match existing supply and demand.

We can therefore conclude that a managing authority which is seriously interested in forging innovative linkages locally would therefore predominantly need to address the issue of matching knowledge supply with knowledge demand. While local linkages in the sense of social exchange can of course always be forged politically, they will only become functional for the national innovation system when the interaction is actually based on technology exchange. This, however, can only occur when the link actually connects supply and demand.

The theoretical considerations above have outlined why and how the knowledge demand of companies in developing countries is rising, that internal knowledge generation has to be complemented by external sources, and that external sources are most efficient when they consist of a firm-specific mixture of international and domestic knowledge suppliers. It has been argued that the sophisticated configuration of innovation systems is not necessarily the result of market forces, but of an intentional design of technology transfer interfaces enabled by public policy. A three-stage empirical analysis will be applied to identify to what degree such sophisticated interfaces are in place in the Chinese innovation system. First, macro indicators are used to identify domestic demand for applied knowledge creation activities in China. Second, the role of the scientific research sector as the major domestic knowledge supplier is characterised by

the scope and limitations of its technology transfer activities. Subsequently, the mismatch between both will be explained. Third, a case study of electronics companies in Guangdong is used to assess their technological needs, their upgrading strategies, and knowledge sources. The analysis will differentiate between domestic, Hong Kong and Taiwan-invested, and foreign-funded enterprises.

Table 1: Chinese Trade Balance in High-tech Products (in US \$ bn)

	2001	2002	2003	2004	2005	2006
Export	46.5	67.9	110.3	165.4	218.3	281.5
Import	64.1	82.8	119.3	161.3	197.7	247.3
Balance	-17.7	-15.0	-9.0	4.0	20.5	34.2

Source: China S&T Statistics Data Book 2007 (NBS 2007)

Table 2: GERD by Type of Activity and Sectors of Performance 2006

	Research Institutes	Higher Education	Enterprise Sector	Total
Basic Research	12.0%	25.8%	0.6%	5.2%
Applied Research	34.6%	49.6%	7.6%	16.8%
Experimental Development	53.5%	24.6%	91.7%	78.0%

Source: China S&T Statistics Data Book 2007 (NBS 2007)

2.5 Development of technological demand in the chinese industrial sector

During the 1990s, there was general agreement in academic discourse that innovation was likely to remain centred in the countries of the so-called Triad and a number of catching-up economies of limited size (Bell/Pavitt 1997; Patel 1995; Patel/Pavitt 1991). Systems beyond the scope of this central nexus of global knowledge generation were usually regarded as "learning" rather than "innovation" systems (Hobday 2000; Viotti 2002). These days, however, are gone. The international geography of innovation has changed substantially since India and China entered the stage.

Today, media coverage suggests almost weekly that innovative activity in these countries, particularly China, is no longer a matter of absorptive capacity only (Cohen/Levinthal 1990; Humphrey/Schmitz 2002). Some Chinese firms have proven themselves able to learn beyond imitation and adaptation, to overcome established power relationships and to acquire particular knowledge which gives them leverage (Medcof 2001; Medcof 2007; Xie/White 2004; Xie/Wu 2003). In more than isolated

cases, in China OEM manufacturing is being replaced by ODM (or even OBM) manufacturing, at least for domestic markets. In some fields such as mobile telecommunications, China is arguably beginning to become a lead market, at least with regard to technological design (Chen 2007).

A strand of academic literature evidences that, in recent years, research activities by multinational corporations (MNCs) in China have surged. Many case studies indicate that they are beginning to make substantial contributions (Chen 2007; Medcof 2007; OECD 2007: 32; Sun/Wen 2007) which may in fact even be understated, as MNCs are likely to downplay the extent of their R&D outsourcing for political reasons (Walsh 2007). Additionally, China's high-tech trade balance has in recent years shifted from a clearly negative figure in 2001 to a clearly positive figure in 2006 (cf. table 1). However, assembly activities in export processing industries may slightly distort this picture as will be discussed below.

At first sight, an analysis of the Chinese innovation system seems thus to suggest that enterprises have become the main drivers of research, an assessment seemingly confirmed by a view of the distribution of expenditure for research and development (cf. table 2).

In practice, however, domestic enterprises have a comparatively weak position in the overall system of technological learning. Enhancing their innovative capacities has been the challenge of the past years and will remain so for the years to come (OECD 2007).

Firstly, more than 91.7% of expenditure in the enterprise sector is currently spent on experimental development, a large share of which cannot really be considered pre-competitive industrial research, but rather constitutes adaptation and process development (cf. table 2). Some authors even presented anecdotal evidence that "R&D is [also] used to refer to the production of additional generic products particularly for China" – in short: copies (Webber 2005: 122 for the Chinese pharmaceutical industry). Even Zhongguancun, the nation's flagship electronics science park in Beijing, does not generate internationally competitive products and has for a long time served as an import nexus of foreign technology rather than as a generator of technological innovation. This statement is taken from interviews with former chairmen of two of the nation's foremost technology enterprises, Lenovo and Stone (Cao 2004: 657, 660).

Secondly, much of the seeming surge in Chinese high-tech exports is in fact generated by re-assembly of imported products. While it is difficult to underpin this finding with reliable figures, it is striking that in 2005 more than three quarters of Chinese high-tech exports were based on "processing with imported materials", with another 15% being

based on "processing with supplied materials" which covers another legal arrangement of delivery and production which does not exclude the possibility that the materials are supplied from abroad (cf. table 3). Even though some ambiguity remains, due to the legal definitions, it would be safe to claim that hardly more than a third of Chinese exports labelled as "high-tech" can be regarded as embodying a majority share of Chinese-generated technology content. Naughton (2007) argues that many of the exports which are technically labelled "high-tech" should in fact be better labelled "labour-intensive". Additionally, foreign invested enterprises make up 80-90% of total Chinese high-tech exports (NBS 2006c; Schwaag-Serger/Breidne 2007).

Table 3: Composition of China's Export of High-tech Products (in US \$ bn)

	2002	2003	2004	2005
General Trade	4.1	6.6	9.9	13.1
Processing with Supplied Materials	11.5	16.5	24.8	32.7
Processing with Imported Materials	49.5	82.7	124.0	163.7
Others	2.7	4.4	6.6	8.7
Total	67.9	110.3	165.4	218.3

Source: China S&T Statistics Data Book 2006 (NBS 2006c)

Undoubtedly, for Chinese managers, even though general wage levels have now risen somewhat, there are still more economic incentives to become active in a non-technological field than to invest in research. From a business perspective, it remains in many cases completely reasonable *not* to invest in pre-competitive business research. While it is often argued that the exposure to world markets can constitute a pull-factor for innovative activities, this is arguably not the case for a catching-up country like China whose companies find it is very difficult to establish themselves in the saturated markets outside their home country without yet being at the forefront of innovation.

Currently, a great deal of research activity is in fact conducted either by foreign subsidiaries, a selected number of government-sponsored public enterprises or a combination of both (Segal 2003). Current studies actually demonstrate that it is the pro-active involvement of the Chinese government in first tier cities like Beijing and Shanghai which makes them favourable locations for foreign R&D centres (Sun/Wen 2007).

On the other hand, some authors have argued that "the asymmetry of technological capabilities between MNCs and local firms poses the danger of motivating the local

firms to give up on technological development and focus only on [complementary] collaborations with MNCs."(Chen 2007: 398).

A study by Sun (Sun 2002) has analysed the relevance of different sources of innovation in large and medium-sized enterprises (LMEs) in China. The results suggest that in-house sources are most important, and that high barriers to absorb external technologies limit the efforts to engage in international technology transfer. A major reason for this fragmentation of the Chinese innovation system is the lack of domestic interfaces, i.e. domestic markets for technology are not efficiently linked to companies' needs (Sun 2002: 1068-1069).

However, newly available data suggest that the amount of S&T outsourcing by LMEs is increasing, as many LMEs who had half-heartedly conducted research in-house have now instead turned to buying technological knowledge and concentrate on their own core competences (Motohashi/Yun 2007; Yao 2006; Zhong/Yang 2007: 323). While this is good news as such for the development of linkages in the innovation system, it is less clear what it actually means for the technological upgrading of the companies themselves. Arguably, it can also be read as an indication of a trend away from at least the absorptive capacity for research cooperation towards technology acquisition by means of technological content in products.

Even the small number of Chinese enterprises that have in fact gained international visibility are actively trying to source technology from abroad, rather than developing technologies themselves. Prominent examples are the cases of Lenovo and IBM as well as Wanxiang car components, which tries to source from Japan (Sigurdson 2005: 84). Genuine innovative activity in the Chinese-owned enterprise sector seems to be confined to a few single enterprises like Huawei, which in 2004 was responsible for 80% of all patenting in the Chinese ICT sector alone (NBS 2006a).

In conclusion, one could argue that there has undoubtedly been significant and unprecedented upgrading in the Chinese technological sector. Nonetheless, one should not be misled by the few isolated lighthouses and beacons that the high-tech sector has developed. On a broader scale, the technological capacities of those enterprises that are the drivers of economic growth in the country remain moderate indeed.

3 Development of technological supply in the Chinese domestic research sector

3.1 General framework

The Chinese public research system, the main performer of the little research conducted in socialist times, has been considerably down-sized and modernised through a series of reforms since the mid 1980s (OECD 2007: 35).

One defining characteristic of public sector research reform was the large-scale privatisation of more than 1,000 public, often applied, research institutes (OECD 2007). In fact, it is often argued that much of the R&D expenditure realised in the private sector is effectively spent by these former public research institutes. The extent to which the phenomenon plays a role is, however, difficult to assess (OECD 2007: 31).

Another key point was the resurgence of the universities as important players in research which they had not been allowed to perform during the planned economy era when the "Soviet model of innovation" restricted their role to education (Kroll 2006; OECD 2007: 35).

For the remaining non-privatised institutes, the structural reform of the system resulted in a reorientation towards basic and strategic research even before this was made a prime objective of national policy. The Chinese Academy of Sciences (CAS), for example, was significantly restructured and is actively working to reach the efficiency required from a player in a market innovation system. The development of China's scientific output indicates that significant progress has been made in this direction (cf. table 4). Nevertheless, the CAS remains a national particularity in that it unites the task of research policy design, political debate, research administration and research performance under the roof of one quasi-ministerial institution. It is in this sense a landmark of the current approach to research policy design and the allocation of R&D funding in China (OECD 2007: 35).

The undeniable merit of the mentioned reforms was that an integration of the innovation system has been achieved among a limited number of high-capacity actors, including the country's most prominent universities, the leading research institutes (most notably the CAS), and a limited number of high-tech companies, both domestic and international. In the course of this paper, we will refer to this as the "island of innovation". As such, this was a considerable improvement on the situation of the early 1990s when the legacy of the planned economy prevailed and there was hardly any interaction at all. With a view to the fact that the Chinese government often follows the approach of testing a model in a delimited area to then expand it to the overall system,

this achievement has merits beyond its immediate utility. Nonetheless, the current density of linkages in the innovation system outside this "island of innovation" leaves considerable room for improvement. In our view, this is a particularly relevant issue, as one may argue that it may be beyond the government's capacities to support and enable the overall system in the same case-by-case manner in which it currently supports the "island of innovation". We would argue that modifications to the overall approach will become necessary when the innovation system is to be extended beyond the high-tech parks – just as happened when the market economy was extended beyond the scope of the Special Economic Zones.

3.2 Structural characteristics

A look at the source of research funds and the sector of performance clearly reveals the defining characteristics of the Chinese research system with regard to public research (cf. table 5). Remarkably, besides the fact that 88% of expenditure is devoted to applied research and experimental development, the share of the public research institutes in Chinese domestic invention patenting decreased from 24.3% in 2003 to 13.9% in 2006. There has been a limited absolute increase in numbers at times where patenting in the higher education sector nearly doubled, reaching more than double the number of research institutes' patents, despite the fact that R&D expenditure amounted to less than half of that by the research institutes.

Public research institutes are, for example, the almost 150 National Engineering Research Centers (NERCs)¹. Since the beginning of the 1990s, the National Ministry of Science and Technology started to establish a series of NERCs to accelerate China's S&T development in high-technology areas by converting scientific research results into useful, economically viable products, solving engineering problems in key areas of industrial development, and exploring ways to integrate science and technology into the economy. Many of the NERCs also operate companies for quick commercialisation and transfer of new technologies. In practice, researchers in the public sector, especially in the restructured research institutes such as the NERCs, have weak incentives to collaborate with players from the industrial sector (OECD 2007: 41). The funding for the NERCs has never set any clear incentives towards their officially proclaimed task of pre-competitive, applied research. Additionally, it is to be phased out in the nearer future leaving many of the institutes to share many other institutes uncertain destiny of de facto privatisation leaving them to perform a role of industrial development they can hardly fulfil (Zhao 2008). Furthermore, beyond a joint

¹ <http://gr.china-embassy.org/eng/kxjs/gjjh/t146173.htm>, <http://www.cnerc.gov.cn/>

presentation on the internet (Chinese language only), there is so far no independent umbrella organisation which could unite these institutes in lobbying or in the other direction constitute a common contact point making them addressable to policy-makers as a community rather than singular entities. As it is, their only policy-contact rests with the immediate programme administrators. In the coming five years, however, the NERC scheme is to be complemented by the newly set up National Engineering Laboratory (NEL) scheme – opening up opportunities for organisational innovation (Zhao 2008).

In addition to these national initiatives, a number of regional public research institutes are emerging, which at least in the case of the two first tier cities may develop substantial momentum in the coming years (e.g. Beijing Academy of Science and Technology, Shanghai Academy of Science and Technology²). In these developments, we see a regional diversification of research supply which is not a bad thing as such (to be witnessed in most leading economies), but increases the need for umbrella organisations and mediating agencies to make it accessible to the industrial sector.

Table 4: Domestic Invention Patents by Sector (Patents Granted), 2006

	2003	2004	2005	2006
Total	6,895.0	12,176.0	14,761.0	18,400.0
Higher Education	1,730.0	3,484.0	4,453.0	6,198.0
Research Institutes	1,677.0	2,406.0	2,423.0	2,553.0
Enterprise Sector	3,382.0	6,128.0	7,712.0	9,433.0
Other	106.0	158.0	173.0	216.0

Source: China S&T Statistics Data Book 2007 (NBS 2007)

Table 5: GERD by Source of Funds and Sectors of Performance in 2006 (bn Yuan)

Source of Funds	Sector of Performance				
	Research Institutes	Business Sector	Higher Education	Other	Total
Government	481.2	96.8	151.5	12.6	742.1
Business	17.3	1946.0	101.2	9.2	2073.7
Foreign Funds	2.6	41.8	3.8	0.2	48.4
Other Funds	66.1	50.0	20.3	2.5	138.9
Total	567.2	2134.5	276.8	24.5	3003.1

² www.bjast.com.cn, www.sast.org.cn

Source: China S&T Statistics Data Book 2007 (NBS 2007)

By statistical definition, the largest amount of funding for public research by far still comes from government sources. Since its realignment, the Chinese public research sector almost exclusively relies on basic funding, with a mere 3% contribution from the business sector. Remarkably, the according to its statutes basic-research-oriented Chinese Academy of Sciences is the exception from the rule, with 44% of its income deriving from market sources (Chinese Academy of Sciences 2007). For the moment the few public research institutes successful in science-industry cooperation are in fact struggling to move away from an application-oriented profile towards basic research and scientific catch-up with the west.

Generally, it appears unlikely that the level of technological supply at the remaining institutes is too high for the domestic enterprise sector. More likely, it is insufficiently adapted and improperly managed. What is currently labelled a "public research institute", therefore, is in its current form unlikely to significantly contribute to the technological supply relevant for the industrial sector (cf. Zhao 2008). Nonetheless, they could have significant potentials for the future, if management is improved.

Quite the opposite is the case in the higher education sector, where the business contribution to the financing of research activities reaches 36.6%. A plethora of university-industry co-operations, joint research labs has emerged (OECD 2007) and at some leading universities the spin-off activities are likely unrivalled by any country outside the U.S. (Kroll/Liefner 2008). Additionally, universities and industrial enterprises jointly participate in government-sponsored research efforts in the main support programmes such as the 863 Programme, the Torch Programme and the S&T Achievement Spreading Programme (OECD 2007: 36).

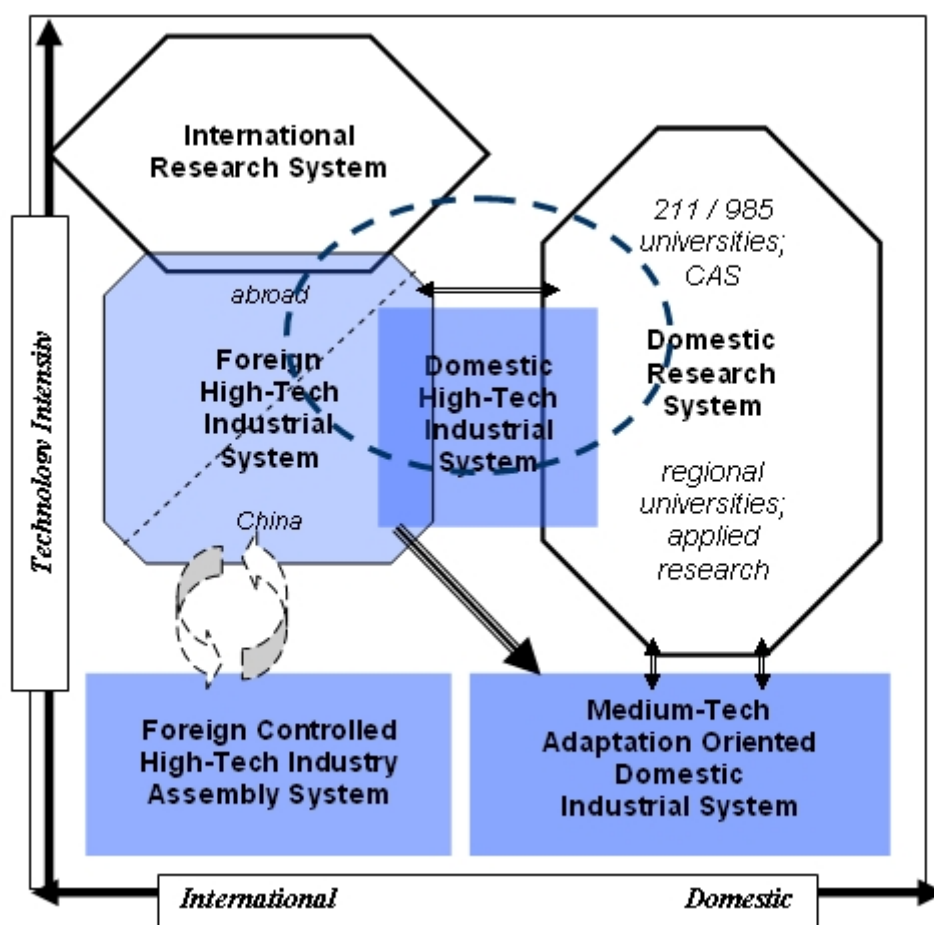
Nonetheless, these activities remain concentrated in the first tier cities (Hennemann 2006; Kroll 2006; Liefner et al. 2006) and limited to a few leading institutions, so that the overall spending on research in the higher education research area amounts to little more than a tenth of overall business expenditure. The business-financed share of higher education research thus amounts to less than 5% of overall business expenditure for R&D. Quite clearly, this is far too little to satisfy the growing technological demand of the industrial sector.

Additionally, it must be taken into account that the current aim of higher education policy is to develop a number of world-class universities with internationally competitive capacities in basic research, as well as educational programmes that can match international standards (OECD 2007: 36). According to the policy-makers' plans, the university system will be stratified into a number of leading research universities (211 Pro-

gramme Programme), a second tier of universities capable of conducting relevant research (985 Programme) and the rest of the field whose main task is to address the issue of qualification (www.moe.gov.cn).

- expenditure in public research institutions is in absolute terms still higher than in the higher education sector
- much of what is termed applied research or even experimental development is in fact financed by the government rather than the enterprise sector
- much of what is called applied research or even experimental development does not seem to result in any substantially applicable results as evidenced by patenting
- overall, there is compelling evidence that the interface between the business sector and the public research institutes is still operating far below its potential capacity
- the higher education sector is a notable exception to this, having reached a degree of business orientation which is realised by few technologically leading countries.

Figure 1: Current Fragmented Structure of the Chinese System of Innovation



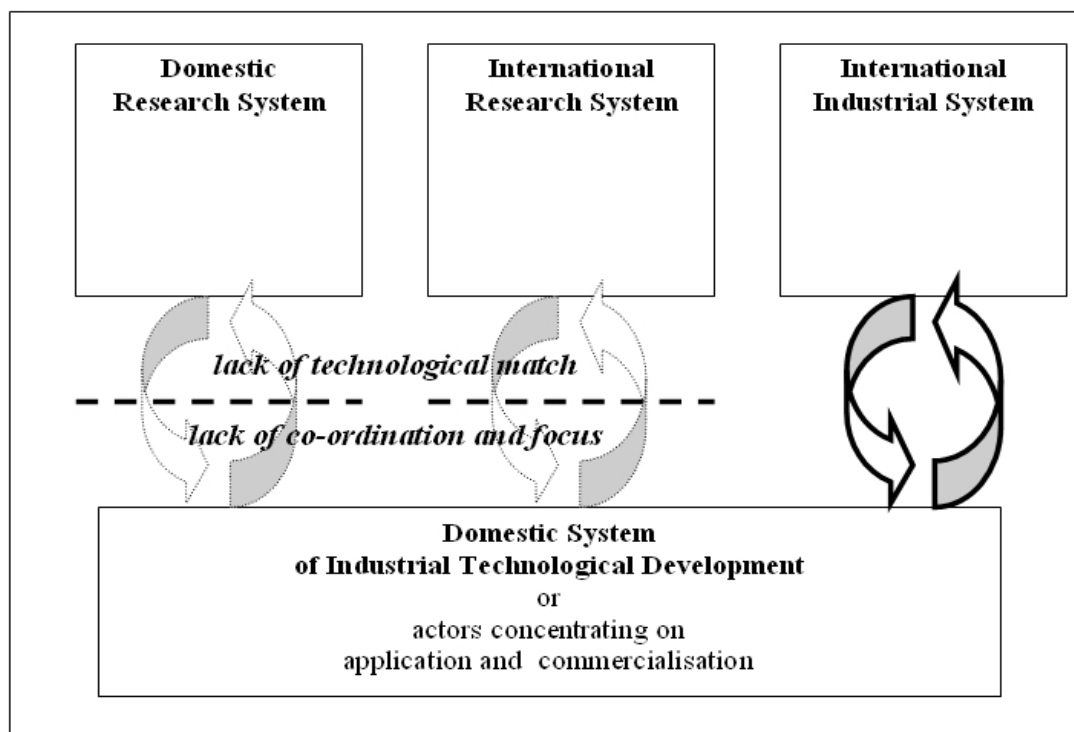
Source: own figure, based on literature review

4 Explaining the mismatch between supply and demand

For the moment, the (mis)match at the interface of technology supply and technology demand in China can be described in the following manner (cf. 1).

- The actors from domestic high-tech industry (as delimited by the HTPs), the top echelons of the domestic research sector (CAS, Tsinghua, etc.) and the limited number of operative foreign R&D centres (cf. Li/Yue 2005) form an insular system of innovation which is characterised by rising interaction, collaboration and, in general, is carefully and consciously managed by the central government. Even the international research system is increasingly involved in these activities. It is, however, insufficiently integrated in the rest of the economy (OECD 2007: 22). Comparatively recent surveys have found that Chinese high-technology enterprises which uniquely rely on domestic knowledge sources are less successful with regard to new product development and technological innovation, despite sizeable R&D intensities (Liefner et al. 2006).
- The foreign-controlled industrial system, even though more than often subject to involuntary spill-overs, does not really interact very closely with the domestic industrial sector. Increasingly, foreign-controlled enterprises actively work to shield themselves against counterfeit activities, limiting the potential of collaboration at a lower scale (Minagawa et al. 2007).
- On the contrary, foreign-controlled companies naturally have close cooperations with foreign R&D centres (of their own group). Those in turn tend to have some linkages with the domestic high-tech sector and the upper echelons of the domestic research sectors, but still mostly work as an organic part of the corporation they belong to (Li/Yue 2005). The interaction between the domestic research sector and foreign R&D labs has in fact often been overstated, as these labs are rarely fully operational and often aim at distributing the MNC's technology rather than initiating actual research cooperations (Chen 2007: 383). In fact, not all of them are functional – it is even unclear if these form a majority (Schwaag-Serger 2006).

Figure 2: Bottlenecks at the Interface between Technology Supply and Demand in China



Source: own figure, based on literature review

- Most of the current technological demand of the broader industrial sector, however, is still satisfied through international knowledge transfer (Chen 2007; Liefner 2006; OECD 2007). Chinese companies either try to copy locally (Minagawa et al., 2007), or source technology from abroad. Cooperation between local companies remains rare outside the designated science parks or high-tech parks (Kroll 2006; Kroll/Liefner 2008).

In any case, while there are quite a number of linkages to the domestic high-tech sector, the medium-tech, adaptation-oriented domestic industrial system as well as the foreign high-tech assembly sector do not benefit substantially from the domestic research system (cf. Zhao 2008) (cf. figure 2). Of course, this is not to deny that some university-industry cooperations do indeed exist on a lower technological level (OECD 2007; Segal 2003). Nevertheless, there is little compelling evidence that, without any supportive intervention, they are likely to grow at a rate substantial enough to satisfy the technological demand of an upgrading industry, let alone reduce China's dependency on external technologies to 30% by 2020.

Hence, we argue that mismatches prevail for the following reasons (cf. figure 2):

- Much of the domestic research sector does not provide an adequate offer for the industrial sector. Even though substantial reforms were successfully carried out, applied research and even experimental development remain the domain of the state. Pre-competitive contract research is not yet sufficiently understood or implemented (cf. OECD 2007; Zhao 2008). Due to this, the actual demand of the industrial sector remains hidden from the domestic players.
- Many of the activities of the domestic research sector beyond its upper echelons are still poorly organised and administered (Zhao 2008: 55). While quality issues undoubtedly continue to prevail, there may just as well be significant untapped resources in the system. For example, to our knowledge, the contribution of the nearly 150 NERCs in the future remains insufficiently explored.
- Support actions of national policy-makers tend to focus on a selected number of projects firmly within the bounds of the "island of innovation" (OECD 2007, Segal, 2003). The concept of public-private partnership is not yet sufficiently understood (OECD 2007:41); the necessity to make enabling subsidies widely available across the board defined by certain criteria rather than for selected projects is insufficiently acknowledged.
- Private sector research outside business enterprises is poorly organised. Other than for example in Germany's Fraunhofer Society, China's public research landscape remains fragmented. Consequently, it is doubtful what contribution the privatised research institutes will be able to make when left on their own, without any central coordinating agency that could prompt reorganisation and reform comparable to that achieved by the CAS.
- It is structurally not helpful that a public research system which is more than 80% focused on applied research and experimental development is financed up to 75% by government sources. This is quite the opposite of the situation in applied research institutions such as the Fraunhofer Society in western countries, which are expected to generate about 70% of their revenues from contract research. Even in the Chinese higher education sector, where a mere 26% of funding is invested in basic research, the government share of research funding reaches about 55%.

5 Technological demand in the electronics industry: the case of Guangdong

This case study illustrates technological demands in the electronics industry by using Guangdong province in South China as an example. Micro-level data from a company survey and secondary data from the provincial statistical yearbook will be used to underpin the results derived from the macro-level analysis above.

Guangdong province is one of the economic centres of China and contributes 10% of the total economic value-added, about 30% of the exports, and about 20% of the inflow of foreign-direct investments. The electronics industry has been the main driver of economic growth in the province during the last years and is responsible for one-third of the provincial value-added in 2006 (Statistics Guangdong 2008).

The technological performance of the province has been much lower than that of the Bohai and Yangtze region. The national average of R&D expenditure per GDP has been 1.3% in 2005. Beijing has reached 5.6%, Shanghai 2.3%, and Guangdong 1.1%, ranking 10th among all provinces. The R&D spending of LMEs in Guangdong is the highest among all provinces, but higher education and public research institution's R&D expenditure are just ranking 8th and 15th respectively (NBS 2006b).

The ownership structure of the electronics industry in Guangdong is diversified. It has been dominated by relocated export processing activities governed by companies from Hong Kong, Macau, and Taiwan (HMT) in the past. Subsequently, other multinational companies moved in, e.g. US-based global contract manufacturers like Flextronics, and local Chinese companies emerged. The latter group consists of thousands of private SMEs and a few large electronics companies like TCL and Huawei. Today, 28% of the value-added are realised by HMT-invested companies, 29% by other foreign companies, 30% by domestic private companies and 10% by state-controlled companies. The share of foreign- and HMT-funded companies even exceeds 70% In the electronics industry (Statistics Guangdong 2008). It will be shown that the need for knowledge and innovation inputs differ markedly among these groups and are not always consistent with the high-tech initiatives pursued by S&T policy makers.

The analysis is based on a company survey conducted in Guangdong province at the end of 2007. This survey mainly focussed on firm organisation, but contained several questions regarding upgrading strategies and innovation activities. It was carried out between November 2007 and February 2008. Companies have been randomly sampled in the municipalities of Dongguan and Guangzhou. The total sample consists of 222 electronics companies which have been contacted by a mailing and interviewed via telephone. In addition, secondary data from the Guangdong Statistical Yearbook 2007 (Statistics Guangdong 2008) and information from company surveys conducted by the Federation of Hong Kong Industries (FHKI, 2007) and the Hong Kong Trade Development Council (HKTDC 2007) are used to substantiate evidence provided by our data.

With reference to the importance of industrial knowledge demand that we have discussed above we will use our data to test three hypotheses:

H1: Foreign-funded firms are more actively engaged in innovation activities than domestic firms.

H2: Firms with close linkages to Hong Kong and Taiwan are less innovation-oriented than other foreign-funded firms.

H3: Chinese firms are more reluctant to get involved with cooperative research with other firms or universities and research institutes than foreign firms.

Guangdong electronics companies have been asked whether they had any innovation activities during the last three years according to the OECD definition. Table 6 shows innovation activities differentiated by the main owner. Taiwanese and other foreign-owned companies are in general more often reporting innovation activities than domestic and Hong Kong firms. The sample of the Chinese domestic sector has not been divided any further since it is limited to private-owned and collective companies. State-owned companies are rather rare in electronics. Other significant influences on innovation activities are the age and the size of firms. Younger and smaller firms are innovating less frequently.

The survey results are substantiated with secondary data on the correlation between the relevance of different ownership types and expenditures on R&D and innovation in the 19 municipalities of Guangdong province. This analysis is not limited to the electronics industry, but table 7 confirms the general trend of the survey results. Foreign-funded firms are ahead of HMT-funded firms and domestic private firms. State-owned enterprises are the least innovation-oriented group.

Table 6: Share of Companies with Innovation Activities of Guangdong Electronics Firms

	ownership				year of foundation		employment size		
	Chinese	Hong Kong	Taiwan	others	before 2000	2000 and later	less than 100	100 to 499	500 and more
yes	67%	72%	81%	77%	77%	66%	54%	79%	82%
no	33%	28%	19%	23%	23%	34%	46%	21%	18%
	n=121	n=39	n=26	n=30	n=107	n=111	n=76	n=81	n=56
χ^2	0,450				0,077		0,000		

Source: own survey

Table 7: Correlations between R&D Intensity and Firm Ownership in Guangdong Municipalities 2006

	value added in % of total			
	state-owned enterprises	share-holding enterprises	HMT-funded enterprises	foreign-funded enterprises
Internal Expenditures for S&T in % of Overall Revenue	-0.49	-0.18	0.13	0.40
Expenditures for R&D in % of Overall Revenue	-0.36	0.01	-0.05	0.28
Expenditures for NPD in % of Overall Revenue	-0.53	-0.09	0.08	0.37

Notes: The values are coefficients of a two-sided Pearson correlation analysis. Guangdong regional data are deficient in that the declared figures of value added for the individual sections of ownership does not add up to the declared total. Consequently, sums for total value added had to be calculated manually.

Source: Guangdong Statistical Yearbook 2007

The innovation orientation is analysed in more detail by looking at firm strategies. Firms without innovation activities are much more short-term-oriented or responding to incoming orders without any specific strategic orientation (table 8). Notwithstanding the results from table 6, Taiwanese firms fall behind Chinese-owned firms when it comes to long-term innovation orientation. On the other hand, Hong Kong firms are pursuing more long-term strategies than one could have expected by the level of their innovation activities.

Existing research on the strategic orientation of Hong Kong firms supports the observation from the survey data. The success of Hong Kong has been based on a distinct upgrading path. It has not been dominated by heavy investments in R&D and innovation, but by entrepreneurs who quickly seized market opportunities in mature markets (Davies, 1996; Yu, 2000). A recent survey on upgrading strategies of Hong Kong SMEs confirmed that just 18% of the SMEs are planning to invest in R&D even though most companies are planning to improve product quality (53%) and designs (45%). While facing rising production costs in the PRD, HK firms are rather planning to strengthen inventory control (37%) or to automate production (36%) than to abandon their export processing business (25%) (HKTDC 2007). Policy initiatives for innovation and upgrading should therefore be extended towards non-technical activities, i.e. design capabilities, new organisational models, etc.

The importance of methods and sources of innovation provides further insights into the technological needs of companies in Guangdong. 85% of the surveyed companies are ranking in-house R&D and innovation activities as important or very important, while only 37% are cooperating intensely during the innovation process. Significant differences of the cooperation intensity exist among firms by their ownership. 45% of the Hong Kong and 52% of the Taiwanese firms cooperate intensely or very intensely, despite 31% of the domestic and 27% of other foreign-firms. This indicates that foreign firms might be much less embedded within the Chinese innovation system than others, and receive much of their knowledge from parent companies (see table 9). The internally-oriented innovation behaviour of Chinese firms might hint at lacking absorptive capacities to cooperate with others.

The most important source for innovation-related information are qualified workers, followed by related companies, fairs, and technical markets. Other companies, universities, and research institutes are the least important sources. Since these results are in clear contrast to the rising importance of universities in the Chinese innovation system it could hint at the non-integration of Guangdong companies in the 'innovation island' identified above, based on the limited presence of central actors of public research in Guangdong.

The in-house orientation of Chinese firms is again proven by this data. Qualified workers are by far the most important information source for these companies, while foreign companies are much more intensely interacting with related companies, i.e. affiliates, customers, and suppliers. It is remarkable that only Hong Kong companies are using universities and research institutes as a knowledge source to a somewhat higher degree. This observation fits with recent results of a survey by the Federation of Hong Kong Industries (FHKI 2007: 85). Companies in the PRD are least satisfied with local universities when valuing the environment for production operations in Guangdong. Only those located in Guangzhou provided a higher satisfaction score (FHKI 2007: 85).

Table 8: Strategic Orientation of Guangdong Electronics Firms

	innovation activities		ownership			
	yes	no	Chinese	Hong Kong	Taiwan	others
long-term focus on upgrading and innovation	66%	28%	53%	62%	42%	68%
short-term opportunities in established markets	12%	20%	14%	13%	27%	11%
just responding to incoming orders	5%	28%	14%	10%	12%	4%
other strategies	16%	25%	20%	15%	19%	18%
	n=154	n=61	n=118	n=39	n=26	n=28
χ^2	0,000		0,595			

Source: own survey

Table 9: Sources for Innovation-related Information of Guangdong Electronics Firms

	all companies	ownership			
		Chinese	Hong Kong	Taiwan	others
hiring qualified workers	54%	56%	45%	62%	50%
		0,449			
customer/supplier	45%	35%	48%	48%	50%
		0,568			
parent/affiliated company	37%	20%	45%	57%	64%
		0,001			
fairs/technical markets	31%	31%	35%	33%	27%
		0,624			
other company	23%	23%	14%	29%	27%
		0,330			
university/research institute	18%	17%	24%	5%	14%
		0,155			
	n=156	n=149			

Source: own survey (Share of "important" and "very important" on a Likert-5 scale, χ^2 values in italics)

The presented results have in general confirmed the three hypotheses, but also provided evidence for further differentiation.

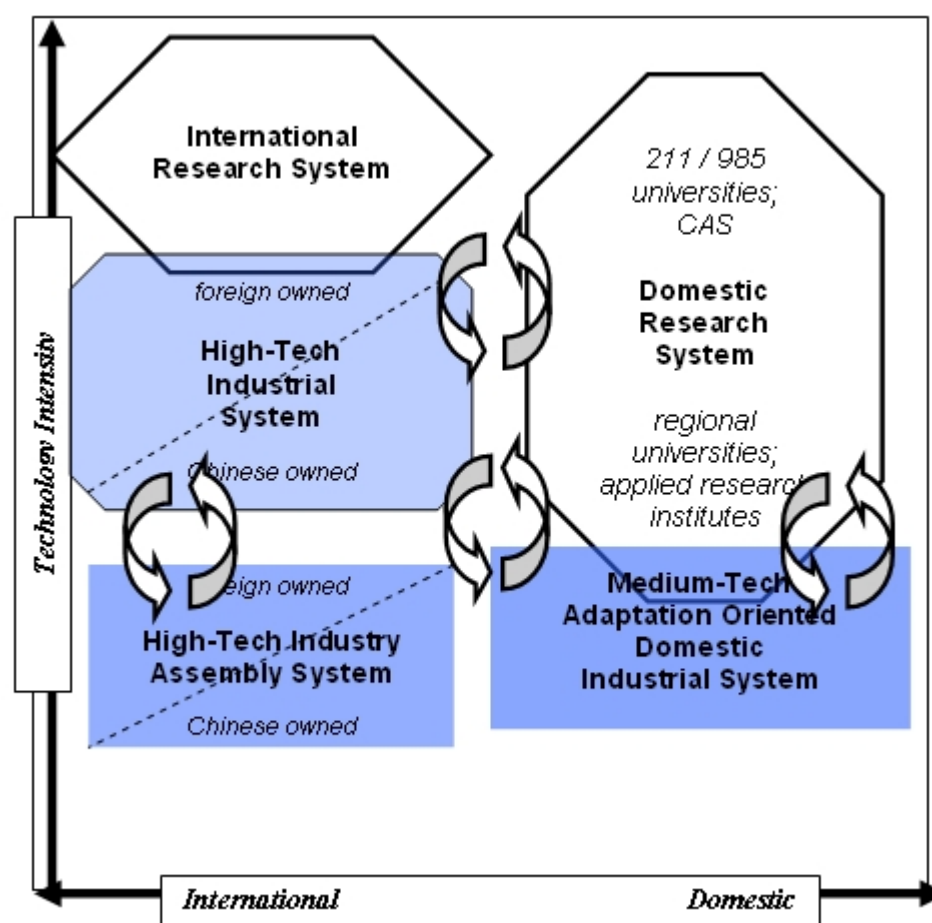
First, the technological needs differ within the broad groups of domestic and foreign firms, i.e. Hong Kong firms are less regularly pursuing innovation activities than other internationally-oriented firms. The same holds true for state-owned companies in comparison to their private domestic counterparts.

Second, the needs of smaller and younger companies have to be addressed with specific programs since their innovation patterns is distinct from larger companies which are more likely to have access to national S&T programs or international technology transfer. The long-term strategic orientation of domestic firms is a potential that could be used by S&T policy makers to link yet too much internally-oriented innovation activities with other knowledge providers, e.g. cooperation with other companies or the public research system.

Third, the role of universities as a knowledge source for innovation is still limited in Guangdong and is symptomatic for the weakness of the public research sector in Guangdong. Direct interaction with universities is in general much less important than hiring of qualified workers, whose availability also depends on good universities. Guangdong province as a whole shows a lack of excellent universities except for two 211/985 institutions in Guangzhou, Sun Yat-sen University which ranks 10th to 15th within China (www.arwu.org) and South China University of Technology. Recently, major national universities, e.g. Beijing and Tsinghua University, opened satellite campuses in the province's most dynamic municipality Shenzhen, but the expansion of higher education institutions did not keep pace with the economic development of the region.

6 Policy conclusions

So far, most current studies agree that Chinese policy-makers have not yet fully realised the practical implications of the interactive (Kline/Rosenberg 1986) and often market-driven nature of innovation (e.g. OECD 2007; Schwaag-Serger/Breidne 2007).

Figure 3: Desirable Future Structure of the Chinese System of Innovation

Source: own figure, based on literature review

Firstly, we would argue that the Chinese government should continue to regard the domestic and the foreign-owned business sector as complementary. Against the background of the current situation, it seems unlikely that the domestic research sector will be able to satisfy the rising technological demand without the complementary knowledge inflow of international technology transfer within the business sector. Given the structural characteristics laid out above, we would argue that a sustainable strengthening of the domestic sector can only be achieved if the fragmentation of the innovation system on the business side is ameliorated. This, however, requires a better rather than a worse integration of the domestic and the international business sector. With the rising technological level of the domestic sector, we believe that such integration is realistic and should be encouraged (cf. figure 3). Consequently, the Chinese government should design public support policies for the enterprise sector in a non-exclusive manner, even if a certain focus on the domestic sector is justified, given its greater need for technological catch-up.

Secondly, the successful match of technological supply and demand is inhibited by the informal nature of Chinese RTDI policy-making, which works sufficiently well within the boundaries of the "innovative island" but makes it very difficult to devise rule-based, across-the-board strategies. Recent Chinese history suggests that this can only be changed gradually, if at all. Hence, it would be naïve and probably not even desirable to ask for a complete turnaround in the process of policy-making which needs to remain specific to an individual country's needs. Nonetheless, it seems that the new policy initiatives in the context of the 15-year plan have generated momentum for restructuring which becomes evident for example in the NEL programme (Zhao 2008). In our view, policy makers need to realise the key importance of this issue and to take action in the following fields:

- The organisation of the public research system must be improved. Any substantial reform of the public, pre-competitive, applied research sector is unlikely to occur if all capacities are fragmented and there is not even any umbrella organisation of the institutes in question.

Even if a central administration of the public, pre-competitive, applied research sector in China is unlikely to be created anytime soon, a first "common representation" (such as the German WGL) could significantly improve the availability of information about technological supply and help institutes to articulate their wishes in the political arena.

- The incentive system has to be changed. Any future association of public applied research institutes in China would need to be dependent on industrial revenue rather than state support. It will be indispensable on the one hand to force researchers to adapt their supply to the existing demand while simultaneously offering significant premiums in case of success. However, the continued allocation of a certain share of public funding will be crucial to ensure the pre-competitive nature of research and to avoid a drift towards mere industrial development.

Germany's "Fraunhofer model" with its 30% public to 70% contract research funding could serve as a template. While institutes are started with a higher share of public funding they face a clear timeframe until which must reach this mix which could be adapted in China.

- The success of the higher education sector should be taken as a benchmark of success which should be further developed beyond the few regions in which it has become particularly successful. Despite the necessary differentiation of tasks among universities with different capabilities (985 Program etc.), there certainly remains untapped potential for university-industry co-operation.

The German support programme for research in universities of applied sciences could serve as a source of inspiration. As in China, these universities are firmly under the administrative roof of the regional governments and their classical mission has been education rather than research. In recent years, however, public support

programmes at the national level have helped to unlock the dormant potential of these institutions by offering supplementary funding for research to which the regional governments could not object.

- Enterprise support policies should be put on a broad basis and extended beyond the "island of innovation" – not necessarily at the expense, but at least complementary to the "key projects" and focused allocation in the context of technology support programmes such as 863. The Innovation Fund for Small Technology-based Firms (www.innofund.gov.cn) is a step in the right direction.

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