Determinants of Industrial Innovation in China and the Role of University Research

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Vorgelegt von
Diplom-Volkswirtin
Wan-Hsin Liu
aus Taipei, Taiwan

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Dekan:	Professor Horst Raff, Ph.D.
Erstberichterstattender:	Professor Dr. Johannes Bröcker
Zweitberichterstattender:	Professor Holger Görg, Ph.D.

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Abbreviation

ASTRI	Applied Science and Technology Research Institute
BERD	Business Expenditure on R&D
CEO	Chief Executive Officer
China	People's Republic of China
CIT	Commission on Innovation and Technology
Col.	Column
Eq.	Equation
FDI	Foreign Direct Investment
FG Model	Flying Geese Model
GCI	Geographic Coincidence Index
GDP	Gross Domestic Product
GERD	Gross Domestic Expenditure on R&D
HERD	Higher Education Expenditure on R&D
HK	Hong Kong
HKD	Hong Kong Dollar
ICT	Information and Telecommunication Technologies
ISF	Industry Support Fund
ITC	Innovation and Technology Commission
ITF	Innovation and Technology Fund
KPF	Knowledge Production Function
MSA	Metropolitan Statistical Area
NCTU	National Chiao Tung University
NIE	Newly Industrialised Economies
NIS	National Innovation System
NTHU	National Tsing Hua University
NUTS	Nomenclature of Units for Territorial Statistics
OBM	Original Brand Manufacturing
ODM	Original Design Manufacturing
OEM	Original Equipment Manufacturing
PRD	Pearl River Delta
R&D	Research and Development
RMB	Renminbi

SIPO	State Intellectual Property Office
SME	Small- and Medium-sized Enterprise
SSRC	Social Sciences Research Centre
TDC	Trade Development Council
UICP	University-Industry Collaboration Programme
UK	United Kingdom
US	United States
USD	US Dollar
WSRT	Wilcoxon Signed Rank Test

1 Introduction

The economy of the People's Republic of China (China) has developed rapidly, at a two-digit growth rate on average, over the past three decades of economic reform. It turned to be the second largest economy in the world with gross domestic product of 8 trillions of international dollars in 2008.[1] It is often argued, that China's strong economic growth in the past has been substantially attributed to massive foreign investor's investment and engagement in vitalising and facilitating the development of the low-tech and labour-intensive industries on site. As a result, China has become one of the well-known world factories for especially labour-intensive products with low technical requirements for the global market. In spite of the economic success in these industries, the increasing market competition, labour shortage and the external market instability induced the Chinese government to revise its economic policy, emphasising innovation as the key driver for long-term sustainable economic growth in China in the future. The Chinese economic policy with innovation promotion as focus, such as the 10^{th} (2001-2005) and the 11^{th} (2006-2010) five-year plans should help transform China to become an innovation-oriented country by 2020. To achieve this goal, the Chinese government recognised the crucial role of firms as innovators and inventors but not merely as producers.

Such policy changes towards more innovation and market challenges such as increasing production costs and intensified market competition construct a business environment in China which is similar to some extent to the environment faced by firms in the Asian Newly Industrialised Economies[2] (NIEs) decades ago. These two factors may act like pull and push factors encouraging firms in China to devote themselves to upgrading to increase their competitiveness in the global market. The lack of innovation experience and capabilities may, however, induce firms there to search for support and to source innovation-related knowledge and technologies from various external innovators, in addition to own engagement in research and development (R&D) for innovation.

Among all potential knowledge sources for firms, universities are expected to be of high relevance. Reasons for the expectation of the high relevance of universities are twofold. Firstly, empirical literature including both case studies and econometric

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[1] This is based on purchasing power parity calculations. See World Bank (2009).
[2] Hong Kong, Singapore, South Korea and Taiwan.

analysis for Western economies give some support for the existence of positive spillover effects of university research on industrial innovation in general (e.g. Jaffe, 1989; Mansfield, 1991). Such positive effects are expected to be even stronger in China due to, secondly, the traditional division of labour between universities and firms for many years. Within the traditional division of labour, universities have been mainly responsible for research work, while firms have to focus on production activities (that follow). Thus, in order to innovate efficiently, firms without innovation experience and capabilities in China may prefer to source relevant knowledge from the pool of academic research results as input support. In addition to having universities as knowledge sources, firms' OEM[3] customers are expected to be of substantial relevance as knowledge sources as well against the developing background of firms in China which has been similar to that of their counterparts in the Asian NIEs.

Compared to empirical innovation literature for Western economies, quantitative analysis on innovation of firms and on innovation determinants in China with focus on the role of different knowledge sources using econometric techniques is limited. To fill this gap, this dissertation applies various econometric techniques and analyses different kinds of datasets to investigate the industrial innovation in China and the role of different knowledge sources especially the role of universities in this regard. The different datasets and methods used are expected to provide more comprehensive quantitative evidence to help us understand the on-going industrial innovation processes in China. The analysis is carried out in three steps and the analysis results are presented in the following three chapters in sequence. As the first step, a unique firm-level dataset collected by our own survey among electronics firms in the Pearl River Delta (PRD) in the province Guangdong in late 2007 is analysed in Chapter 2. The dataset provides a series of information with regard to firms' innovation activities such as firms' own R&D engagement, knowledge sources they used and various innovation outcomes they achieved. This enables us to apply firm-level knowledge production function framework proposed by Criscuolo et al. (2005) and Wagner (2006) to investigate whether innovation success of firms in China depends solely on their own R&D engagement; if not, whether knowledge transferred from diverse sources may matter differently for firms to carry out different innovation outcomes. Moreover, based on the evidence

[3] OEM refers to original equipment manufacturing. Firm engaging in the OEM business are normally asked to follow the production instructions of their OEM customers to produce exactly the products designed by the OEM customers. OEM customers normally provide their producing companies advanced machines, technologies and know-how as well.

obtained we attempt to figure out whether similar developing path of firms in China as their counterparts in the Asian NIEs in low-tech and labour-intensive industries may induce further developing similarity regarding firms' upgrading behaviour in both regions.

Consistent with our expectation, estimation analysis in Chapter 2 shows that firms' own R&D engagement matters for certain types of innovation activities but not for all. To carry out process innovation activities efficiently, firms rely more strongly on sourcing knowledge and technological supports from their OEM customers than own R&D engagement. In contrast, own R&D engagement is significantly and positively relevant for firms' product innovation and patenting activities. In the latter cases, firms also source knowledge and technologies as additional innovation inputs but from external innovators other than OEM customers to facilitate their innovation processes. For example, universities – the traditional research sector in China – are found to play a significantly positive role as knowledge sources especially for firms' patenting activities.

The finding of a positive role of universities for firms' patenting activities in the PRD is consistent with related empirical literature for Western economies. But the difference between the analysis in Chapter 2 and the analysis in the empirical literature with similar findings for Western economies in methods for analysis and in types of datasets considered restricts the possibility for a comparison between countries. This motivates us to deepen our research focusing on the role of university for industrial innovation for the whole mainland China using comparable methods and datasets. More concretely, moving from Chapter 2 to Chapter 3 we expand our analysis from being at the firm level to being at the province level, from focusing on the PRD to considering the whole mainland China, and from being based on the one-shot observations to considering annual industrial innovation in China since the new century.

Motivated by the seminal work of Jaffe (1989), Chapter 3 applies the regional knowledge production function framework to analyse the role of universities for industrial patenting activities at the provincial level in China. In doing so, we analyse a province-level dataset of the mainland China[4] for the years from 2000 to 2008. We do not, however, treat all universities in China as being knowledge sources equally accessible to firms and being equipped with the same research potential. Instead, similar to the empirical literature for Western economies, we consider firms' geographic

[4] Tibet is excluded due to data limitation.

proximity to universities in the analysis. Given firms' need for academic knowledge of tacit nature which is expected to be more efficiently transferred via face-to-face communication, universities located closer to firms are expected to have higher positive spillover effects on industrial patenting than universities located farther away. Different from most of the related literature, we consider university difference in research quality, in addition to firms' geographic proximity to universities, in the analysis in Chapter 3. Moreover, we differentiate industrial patenting results into two groups by degree of technological requirements: invention patenting results and non-invention patenting results. We deal with econometric issues such as endogeneity problem, serial autocorrelation and spatial autocorrelation as well.

Estimation results in Chapter 3 suggest the existence of spatial academic research effects on industrial patenting activities in China, although firms' own R&D engagement is found to still matter most substantially for firms' patenting success. Such spatial effects are especially strong for the technologically less demanding industrial non-invention patents. Moreover, geographic proximity of firms to universities dominates over university research quality for determining the relevance of universities as potential academic knowledge sources for firms. Although geographic proximity of firms to universities is found to matter significantly positively for industrial patenting, the magnitude of the positive effect is small compared to the effect of firms' own R&D engagement. This further suggests that firms seem to be relatively cautious about engaging in interactions and cooperation with universities for innovation, though they may actually indeed profit from efficient academia-industry linkages. Firms' unawareness of knowledge supply of universities and interest conflicts between firms and university researchers may be two potential reasons for the less optimal intensity of Chinese firms' engagement in academia-industry linkages. This leads to the next question worth being further investigated, namely whether firms' willingness to engage in academia-industry linkages can be positively affected by corresponding promotion through governmental active innovation policy.

We deal with this active policy issue in Chapter 4 using Hong Kong (HK) which returned back to be a part of China in 1997 and its innovation policy as an example. Due to HK's colonial history and HK (colonial) government's different attitude to support private economic development and upgrading in the pre- and post-1997 eras, HK provides itself as an interesting case for us to learn more about whether active innovation policy carried out in the post-1997 period may positively encourage HK firms to carry out innovation activities in general and to engage in academia-industry linkages for innovation in particular.

The analysis in Chapter 4 is based on available official statistics and on a dataset of electronics firms collected by our own HK Company Survey in 2007. Descriptive statistical analysis is performed to gain insights into innovation engagement of HK firms in general and HK electronic firms' contemporary engagement in different types of academia-industry linkages in particular. Probit estimation techniques are applied to explore the potential impact of active innovation policy on HK electronics firms' willingness for sourcing knowledge from and cooperating with universities, taking into account different firm characteristics derived from the literature. Main results show that HK firms become more willing to invest in innovation activities over the past decade. Their willingness to do so seems to be stronger in the period after the policy change than before. In 2007, HK electronics firms interviewed perceive innovation and upgrading strategy as equally important as cost reduction strategy – that was different decades ago – showing that they are more willing to innovate than before, too. Regarding firms' willingness to engage in academia-industry linkages, among all potential knowledge sources or potential innovation partners universities and research institutes seem not (yet) to be highly relevant for HK firms on average and for interviewed HK electronics firms. However, it seems that relatively more HK electronics firms are willing to source academic knowledge for innovation from universities and research institutes than HK firms in general. Moreover, HK electronics firms tend to rely on hiring highly-qualified labour trained by universities and research institutes to gain access to advanced academic knowledge. Although HK electronics firms do not yet intensively source knowledge from or cooperate with universities and research institutes for innovation, their willingness to do so seems to be to some extent positively affected by the active innovation policy undertaken by the HK government in the post-1997 era. The finding of a positive policy effect on firms' engagement in academia-industry linkages may provide some policy implications relevant for the Chinese government to effectively promote academia-industry linkages in the future. In Chapter 5, policy implications are derived based on a brief summary of the key findings along the research line from Chapter 2 to Chapter 4.

2 The Relevance of Own R&D and Sources of Knowledge Transfer for Industrial Innovation

For the working paper version of this chapter see Liu, W.-H. (2009), Do Sources of Knowledge Transfer Matter? A Firm-level Analysis in the PRD, China, Kiel Working Paper 1578, Kiel Institute for the World Economy (http://www.ifw-members.ifw-kiel.de/publications/do-sources-of-knowledge-transfer-matter-2013-a-firm-level-analysis-in-the-prd-china).

2.1 Introduction

As Chapter 1 indicated, China has developed rapidly over the past three decades and it turned to be the second largest economy in the world in 2008 with gross domestic product of 8 trillions international dollars.[5] After the initiation of the open-door policy in the late 1970s, the economic interactions between China and foreign economies, especially those from Asia, have been intensified with continuous increase in inward foreign direct investments (FDI). Such intensive interactions between China and especially the more advanced Asian economies have been argued to play an essential role for China's rapid economic development. Arguments as such are often related to the 'Flying Geese Model (FG Model)' which was firstly proposed by Akamatsu in the 1930s and further developed by Yamazawa, Kojima and Ozawa over the past decades (Akamatsu, 1961 & 1962; Yamazawa, 1990; Kojima, 2000; Ozawa, 2009). The FG Model suggests a co-development of countries in a hierarchical form with more advanced countries taking the leading positions and the developing countries acting as followers. As regards the economic development in East Asia, Japan was argued to take the leading position, followed by Hong Kong, South Korea, Singapore and Taiwan (Asian NIEs[6]) as the first-tier followers where Japanese companies from the labour-intensive industries started to engage in FDI in the 1960s. With the economic development and the increasing production costs in the Asian NIEs in the 1980s, companies in the Asian NIEs started to relocate more labour-intensive activities into China and some other southeast Asian countries by investing on site just like what Japanese firms did in the 1960s. These new FDI receivers were then included into the co-developing hierarchy as the second-tier followers to take over the most labour-intensive part of the value chains.

[5] To calculate this figure a purchasing power parity basis was used. See World Bank (2009).
[6] The term 'NIEs' refers to Newly Industrialised Economies.

The FG Model attributes the co-development of the developing countries strongly to their integration as followers in the hierarchical development pattern to take over the labour-intensive activities. Such integration is made possible mainly due to the FDI engagement of companies from the more advanced countries. However, taking over labour-intensive activities alone may not sustain the development of the follower countries in the long term. With the economic development and increasing labour costs, followers' comparative advantages in carrying out low value-added and labour-intensive activities may gradually disappear. What kinds of efforts the follower countries may make to climb up the upgrading ladder to sustain their market competitiveness against the other (second-tier) followers is not investigated in detail in the FG Model.

In contrast, one branch of the innovation-based growth paradigm which was developed by Aghion and Howitt (1992) and further elaborated in Aghion and Howitt (1998 & 2009) provides some general theoretical base for the role of innovation activities of profit-maximising firms for driving a country's (long-term) economic growth. Their paradigm further argues that innovations which drive a country's economic growth are carried out through firms' investment in own knowledge exploration and innovation processes and/or through learning and profiting from the knowledge and innovations realised by other innovators in the past. Firms from technologically backward countries are expected to profit especially more from such knowledge spillovers from the technology frontiers. One may go beyond the paradigm and expect, based on the concept of the national innovation system as well, that such knowledge spillovers may not merely occur among firms as innovators across countries with different levels of technological development. Positive knowledge spillovers are also expected to exist among firms with different innovation capability and experience in the same country as well as between firms and other types of innovators such as universities and research institutes.

Take the Asian NIEs as the first-tier followers in Asia as examples, there are some case studies trying to identify the upgrading efforts made by firms in the Asian NIEs in the past. Although empirical literature based on econometric analysis is hardly found, case studies provide some support for the innovation-based growth paradigm proposed by Aghion and Howitt (1998 & 2009) and show that firms in the Asian NIEs, due to the lack of technological capabilities, tended to innovate by relying on using advanced machines and learning technologies provided by their parent companies or

OEM (original equipment manufacturing) customers from Japan or some other more advanced countries so that they can increase their production efficiency (e.g. Hobday, 1995b; Nabeshima, 2004). Moreover, the lack of financial resources and innovation experiences hindered them from devoting themselves to undertaking own R&D activities and reduced their incentives to bear high risks and to develop new products on their own.

Accompanying with the rapid economic development in China, firms in China are facing greater competition than before. Increasing production costs and the changing governmental policies towards innovation and upgrading construct a business environment similar to some extent to that faced by firms in the Asian NIEs decades ago. These two changes seem to act like push and pull factors encouraging firms in China to devote themselves to upgrading to increase their competitiveness in global markets. Following the innovation-based growth paradigm briefly explained above and against the similar developing backgrounds among firms in China and their counterparts in the Asian NIEs and their highly intensive economic interactions with each other in the past, one may expect that firms in China innovate and upgrade in a similar way as firms in the Asian NIEs decades ago – learning from others first and own R&D engagement later. This chapter aims to investigate this issue in more detail and investigate whether firms in China use different knowledge sources to support them to carry out different innovation outcomes. Among all potential knowledge sources considered, we put our focus especially on the role of OEMs and the role of universities in this regard due to China's similarity in developing paths with Asian NIEs on the one hand and due to its traditional division of labour between universities and firms on the other hand.

Different from the case studies carried out in the Asian NIEs, this chapter performs an econometric analysis, using a firm-level dataset collected among electronics firms in the Pearl River Delta (PRD) in China in 2007. It estimates firm-level knowledge production functions (KPFs), based on the KPF concept proposed by Criscuolo et al. (2005) and Wagner (2006). This concept, different from the traditional KPF concepts, considers knowledge and technologies transferred from different sources as innovation inputs in addition to firms' own R&D engagement. Moreover, in order to more comprehensively capture the new knowledge created by companies in the PRD, this chapter considers four different innovation outcomes of firms: innovative products, innovative processes, sales of innovative products and patenting activities.

This chapter is organised as follows. In Section 2.2 we briefly review literature related to the FG Model, upgrading activities of firms in the Asian NIEs, and the innovation-based growth theory of Aghion and Howitt (1998 & 2009) at first. Focusing on the knowledge production processes we review literature related to the traditional KPF concepts and the KPF concept of Criscuolo et al. (2005) and Wagner (2006). The latter KPF concept is used for the analysis in this chapter. In Section 2.3 we introduce the survey background and we summarise stylized facts regarding firms' innovation activities in the PRD using some descriptive statistics. In Section 2.4 we establish baseline and extended estimation models based on the KPF concept and we analyse the estimation results in more detail. Section 2.5 concludes.

2.2 Literature Background

2.2.1 Flying Geese Model, Industrial Upgrading in the Asian NIEs and Endogenous Growth Model

While the Japanese economist Akamatsu started to use the phrase 'flying geese pattern' in 1930s, he used it to describe a fundamental pattern of industrial development in Japan over time, which he identified after examining the evolution of several Japanese manufacturing sectors. Such a fundamental pattern is characterised with firms' import activities at first, which was followed by growing import-substitution industries and domestic production activities. Over time, production techniques become more mature, which makes mass production and export business possible. In 1960s, Akamatsu went beyond the sole industrial scope of flying geese pattern in a single country and extended it into a multi-country concept by adding in two additional patterns which he observed. The first additional pattern describes a developing phenomenon across industries, namely a developing order from focusing on consumer goods to capital goods and from simple products to more sophisticated products over time. To make a more harmonic development across industries more possible, firms in the more advanced countries need to adequately utilise the strengths of developing countries. This constructs the second additional pattern considered by Akamatsu. More concretely, firms in the more advanced countries may relocate the more labour-intensive production activities into developing countries to sustain their price competitiveness in such labour-intensive industries on the one hand. On the other hand, they may be able to more efficiently allocate the scarce resources at home to focus on advanced or more capital-intensive industries. Through the relocation efforts of the companies from the more advanced countries, developing countries obtain resources and chances to be integrated as followers into the cross-country co-developing pattern (Akamatsu, 1961 & 1962; Yamazawa, 1990; Kojima, 2000; Ozawa, 2009).

The FG Model became well-known among economists outside Japan firstly after the rapid economic development in East Asia. Over time, several studies were carried out to investigate whether the FG Model stays valid in explaining the industrial development and transformation within the East Asian countries. Most studies were carried out at the macroeconomic level, using nationwide statistics regarding gross domestic product (GDP), export, and import and using index of revealed comparative advantage based on these statistics. Most economists agree on the validity of the FG Model in explaining the economic development pattern in East Asia in the past, in which Japan had the superior leading position, followed by the Asian NIEs as the first-tier followers and China and some other southeast Asian countries as second-tier followers. Differently, findings from the macroeconomic studies in the new decade seem to be inconclusive (e.g. Tung, 2003; Ginzburg and Simonazzi, 2005; Chiang, 2008). However, relying on macroeconomic studies to investigate the validity of FG Model in explaining the economic development in East Asia may have at least two drawbacks. Firstly, the role of firms which were initially recognised by Akamatsu as the main actors for enabling the industrial transformation across countries can not be adequately investigated. Secondly, statistics used in the macroeconomic studies such as GDP, export and import are output statistics. Relying on such statistics the industrial transformation processes which firms went through over the last decades can not be figured out.

To better clarify the industrial transformation in individual countries in East Asia, some case studies were carried out. Focusing on the upgrading activities of firms in the Asian NIEs as the first-tier followers during their developing phase, Hobday (1995a & 1995b) found that electronics firms in these countries lacked human capital, innovation capabilities and experiences when they started to think of upgrading. In order to climb up the upgrading ladder, they need to learn how to innovate by using imported equipments and absorbing technologies and know-how transferred from external players, instead of devoting themselves to own research and development (R&D) activities directly.[7] Due to the same reasons, they tended to focus, at first, their innovation efforts

[7] Coe and Helpman (1995) and Coe et al. (1997) found that R&D activities undertaken in the more advanced OECD countries may not only affect total productivity growth in these OECD countries.

on improving their production efficiency incrementally. After gaining some more innovation capabilities, they may start to carry out some improvements in their product functions or product design. Based on the mechanisms identified by Hobday (1995a & 1995b) [8] which were used by companies in the Asian NIEs to acquire foreign technologies, the following knowledge sources were assessed especially important: parent company and affiliated companies, OEM customers, technical markets and hiring highly-qualified workers. Among these sources, the first two sources seemed to be of higher relevance especially for the beginning of upgrading activities to overcome the barriers due to low innovation capabilities. The findings of Hobday (1995a & 1995b) obtain some support from the other empirical studies in East Asia. Kim (1991) and Kim and Lee (2002) also argued for, based on their research in South Korea, an inevitably high relevance of OEM customers from which technologically laggard firms may more easily obtain advanced equipments and innovation-related technologies. In addition to relying on equipments imported from the OEM customers or other affiliated companies, firms in East Asia tended to strengthen their innovation capabilities through hiring highly-qualified workers who were well educated or trained overseas (e.g. Kim, 1997). With improving innovation capabilities, firms tried to learn new know-how and technologies in form of reverse engineering, i.e., buying finished products from the competitors in the markets and trying to figure out and to learn the new technologies used by competitors to produce those products (e.g. Kim, 1998; Kim and Nelson, 2000; Kang, 2001). The progress in innovation and upgrading made by firms in the Asian NIEs has been supposed to be the major driver for the strong economic growth of these economies since the 1980s (e.g. Hsieh, 2002).

The findings summarised above which showed the way how firms in the Asian NIEs made progress in innovation and the high relevance of technological progress for the economic growth of these economies is in line with the growth model developed by Aghion and Howitt (1992) and further elaborated in Aghion and Howitt (1998 & 2009), which is recognised as one branch of the innovation-based growth theory. The development of the innovation-based growth theory was a reaction to the deficiency of

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Positive spillover effects of the R&D activities in the OECD countries on the total productivity growth in the developing countries can also be identified. This finding gives additional evidence on the importance of acquiring foreign technologies and knowledge for upgrading in the developing countries. Moreover, Coe et al. (1997) argued that especially East Asian countries benefited a lot from the foreign R&D activities.

[8] The following mechanisms were identified by Hobday (1995a & 1995b): FDI, joint ventures, licensing, OEM, own-design and manufacture, sub-contracting, foreign and local buyers, informal means (overseas training, hiring returnees), overseas acquisition and strategic partnerships for technologies.

the neoclassical growth theory in explaining long-term economic growth. Basically, the innovation-based growth theory argues that long-term economic growth of a country is determined by the growth rate of the total factor productivity of the country, which depends endogenously on innovations carried out by firms in the country. The growth model developed by Aghion and Howitt (1992 & 1998 & 2009) is one branch of the innovation-based growth theory. Their model is usually called as Schumpeterian Model because of its focus on quality-improving innovations and Schumpeterian creative destruction processes as drivers for the long-term economic growth. The focus on quality-improving innovations makes the model distinguished from the other branch of the innovation-based growth theory – the Product Variety Model of Romer (1990).

The Schumpeterian Model for which the empirical research in East Asia provides some evidence was derived from the industrial organisation theory, emphasising the industrial competition for encouraging quality-improving innovations and economic growth. Assumed that all industries are ex ante identical, the economy-wide Cobb-Douglas production function at the aggregate per-worker level of the Schumpeterian Model is as follows:

$$Y_t = A_t^{1-\alpha} K_t^{\alpha} \qquad (2.1)$$

where *Y* refers to the aggregate per worker output, *A* the labour-augmenting productivity, *K* capital stock per worker for production and *t* for time. The productivity growth is determined by quality-improving innovations carried out by profit-maximising firms and such increase further determines the output growth (Aghion and Howitt, 2009).

Firms carrying out innovation activities may engage in own R&D activities to create and realise new innovations and/or in implementing and imitating the existing innovations realised by other innovators (from other countries) in the past. In other words, the productivity increase in the Schumpeterian Model as shown in Eq.[9] (2.2) is driven by firms' frequency (μ_n) in performing own R&D activities and realising leading-edge innovation with $\gamma > 1$ on the one hand and by firms' frequency (μ_m) in implementing and adopting existing innovations to catch up with the high productivity of the world technology frontier ($\overline{A}_t$) with $\overline{A}_t \geq A_t$ on the other hand. The contribution of the implementation and adoption of existing innovations to own productivity increase is larger for firms, technology standard and thus productivity of which lie farther behind the technology frontier. This feature – or called 'advantage of backwardness' according

[9] Eq. means equation.

to Gerschenkron (1962) – is integrated into the Schumpeterian model in order to take into account the potential effect of technology transfer and spillover on productivity increase, which enables a convergence and catching up process of economically backward countries towards the development level of the economically more advanced countries.

$$A_{t+1} - A_t = \mu_n(\gamma - 1)A_t + \mu_m(\overline{A}_t - A_t) \quad (2.2)$$

Firms' frequency in realising leading-edge innovation and in catching up with technology frontier need not be taken as given and constant. Instead, they are determined by several factors which reflect the high uncertainty and risks of firms' research and upgrading activities as well as firms' capability to overcome the innovation challenges and to make profit from selling the innovative products. In particular, in order to carry out leading-edge innovations higher R&D expenditure is expected, the closer the technology status and thus the productivity of firms in a country to the technology frontier. This further implies that whether firms are financially capable of carrying out profitable innovation activities plays also a great role for innovation frequencies. The capability of firms to finance their innovation activities can be determined by not only their own resource endowment but also potential credit constraints and financial market development of the country. In case that firms need to finance their innovation activities via long-term bank credit, macroeconomic stability, e.g. the stability of the interest rates may affect firms' willingness for engaging in long-term and risky innovation activities. In addition to financial resources, whether firms may have access to highly qualified workers is another substantial determinant of innovation frequencies as well. However, this does not necessarily mean that only tertiary education is key for overall innovation. For catching up with the technology frontier, the improvement in average education level through emphasising the primary and secondary education is expected to play an even more important role. Last but not least, intellectual property right protection and institutions fostering competition are expected to affect firms' innovation frequency as well. Better intellectual property right protection makes it possible for firms to appropriate their innovation rents more efficiently and thus encourages them to engage in innovation activities. As regards competition, an inverted U-shape relation between competition and innovation is expected. While competition and lower market entry costs are expected to foster innovation of firms with technology and productivity levels closer to the technology frontier, competition and low entry costs affect innovation less positively if firms' technology and productivity standard lies far behind the technology frontier.

Several empirical studies provide evidence for the role of these potential innovation determinants for the economic growth hypothesised in the Schumpeterian Model. Acemoglu et al. (2006), for example, found a statistically positive correlation between technology proximity to frontiers and R&D intensity, while higher R&D intensity is assumed to be substantial for innovation success. Moreover, they found, based on both cross-sectional and panel data analysis at the country level, that the negative relationship between technology proximity and total factor productivity growth is significantly larger in case of high-barrier countries than in case of low-barrier countries. Their results suggest that firms in high-barrier countries profit more from learning and adopting existing technologies from technology frontier, if they lie far behind. In low-barrier countries, the productivity increase of firms rather needs to be sustained by higher R&D intensity but not just further relying on implementing and adopting the existing knowledge and technologies. Higher R&D intensity can, however, not be sustained in the recession period, when firms do not have sufficient resources for financing innovation activities and additionally are faced with higher credit and financing constraints over the market. In this situation, countercyclical economic policy is expected to be of substantial relevance for encouraging further innovation-based growth. Countercyclical policy may also help sustain macroeconomic stability which was found to encourage economic growth as well (e.g. Aghion and Marinescu, 2008; Aghion and Durlauf, 2009). Beyond the influential factors related to financial resources for innovation, the analysis of Aghion et al. (2005) provided empirical support, based on the cross-state US data that investment in tertiary education is also important for encouraging economic growth. However, such positive effect was found especially larger in states closer to the technology frontier. Instead, investment in lower-level education was found to be more substantial for enhancing growth in states lying far behind the technology frontier. Most of these studies regress the growth rate of the economy or that of the total factor productivity over a spectrum of innovation determinants. In fact, total factor productivity increase is driven by a part of new knowledge created only which is further codified, embodied and applied in producing several different kinds of innovation outputs for being sold and used in the economy. Innovation inputs which firms invest in their innovation activities and different institutions and regulations may affect firms' knowledge creation processes with various innovations as outputs to different degrees. Such difference is left in the black box if empirical studies analyse the relation between the economic growth rate or the growth rate of total factor productivity and several potential innovation determinants only. In contrast, the development of the concept of Knowledge Production Function by Griliches (1979) makes it possible to follow the research idea to investigate the relation between innovation inputs invested and new knowledge created.

2.2.2 Concepts of Knowledge Production Function (KPF)

The basic concept of KPF, which was first introduced by the seminal work of Griliches (1979), refers to the relationship between R&D expenditure as innovation inputs and patented inventions as a proxy of knowledge newly created in the knowledge production processes. In other words, under the first trial of estimation of the KPF one assumes that the productivity levels of firms are a result of new knowledge created by them. Since new knowledge created is difficult to observe and measure, patent statistics are used to proxy (a part of) the new knowledge created. The concept of KPF thus assumes that the amount of patents invented is a function of innovation inputs, R&D expenditure in particular, invested by innovation firms. The first innovation studies of this sort analysed firm-level datasets and found a significant role of R&D activities for the production of patents. However, such relationship was found to be especially significant in the cross-sectional (firm) dimension but less significant in the time dimension (Pakes and Griliches, 1980a & 1980b).

The basic concept of the KPF has been extended in different ways to better analyse the relationship between R&D activities and innovation outcomes. Firstly, Griliches and Mairesse (1984) extended the basic KPF into an R&D-augmented production function to analyse the role of labour, physical capital and R&D capital for firms' value-added outputs in the US. Their finding was similar to the finding of Pakes and Griliches (1980a & 1980b). Secondly, Jaffe (1986) further developed a system of equations based on the basic KPF, in order to better estimate the spillover effects of knowledge created by neighbouring firms on firms' performance in the US. He found that the R&D activities undertaken by neighbouring firms indeed positively influence firms' production of patents. Also Jefferson et al. (2006) applied a system of equations for their analysis on the R&D performance in the general Chinese context. The system of equations applied by them was, however, built in a recursive way and included a function of R&D expenditure, a KPF and a performance function. The performance function considered both usual production factors and innovation outputs resulted from the KPF as inputs. In this way they found robust and significant contributions of firms' R&D activities to their new product sales, productivity and profitability.

However, engaging in innovation activities requires not only investment in R&D but also other inputs such as human capital, materials, and internally and externally accumulated knowledge stock (Stoneman, 1995; Aghion and Howitt, 1998 & 2009). Besides, patents and innovation sales may not sufficiently capture the knowledge newly created and thus underestimate the relevance of certain innovation inputs for firms' innovation results. To more comprehensively analyse innovation activities, several attempts have been undertaken to extend the basic KPF in a way, taking some other innovation inputs and innovation outputs into consideration. For example, Hu et al. (2005) analysed the potential effects of technology transfer and foreign direct investment (FDI) on firms' productivity. They found, in addition to a positive role of R&D for firms' productivity, a complementary relationship between R&D and technology transfer either from other domestic innovators or from abroad.

Criscuolo et al. (2005) and Wagner (2006) considered a more detailed differentiation of technology and know-how transferred into firms from different sources in addition to firms' own R&D engagement as innovation inputs for firms' innovation activities in the United Kingdom (UK) and Germany, respectively. In doing so, they were able to investigate whether only own R&D engagement matters substantially for firms' innovation success in these two technologically advanced countries – as hypothesised based on the Schumpeterian Model – or whether learning from others is still relevant in this regard. Moreover, they were able to, due to the detailed differentiation of various knowledge sources, investigate whether the effects of learning from others on own innovation success may differ across knowledge sources considered. Both Criscuolo et al. (2005) and Wagner (2006) also considered firms' export engagement in addition to (inward) FDI as potential determinants for firms' different innovation behaviour, based on the idea that such global economic engagement may support firms to access existing knowledge and innovations realised by advanced innovators abroad. As innovation outcomes, they considered sales of innovative products in addition to patents. While Criscuolo et al. (2005) considered product and process innovation as another innovation outcome, Wagner (2006) focused only on innovative processes as his third innovation outcome for analysis. As result, they found, interestingly, that firms' own R&D engagement does not always matter significantly for their innovation success. Instead learning and sourcing knowledge from others was found to play a role as well. Knowledge transferred from different sources matters to various degrees for innovation outcomes considered, however. Their results suggest that firms investigated, although they are located in technologically more advanced countries like UK and Germany, technologically may still lie behind other types of innovators when different innovation outputs are considered. This leads to different degrees of relevance of different knowledge sources for supporting firms' innovation success.

The KPF concept of Criscuolo et al. (2005) and Wagner (2006) was, to the best of our knowledge, not yet applied in the Asian context. Its advantage to investigate the relevance of different innovation inputs, including own R&D engagement and learning and sourcing knowledge from other advanced innovators, for various innovation outputs induces us to apply this KPF concept for our further analysis, focusing on gaining more insights into firms' innovation behaviour in China. The KPF concept applied in its general form is as follows:

$$\Delta KN_i = f(RD_i, KNT_{ii}, KNT_{i\_i}, X_i) \tag{2.3}$$

where ΔKN refers to the new knowledge created which is further proxied by various innovation output indicators like patents and innovation sales and i refers to firms. The creation of new knowledge is a function of R&D inputs of innovators (RD), knowledge transferred within innovators (KNT_{ii}), knowledge transferred from external innovators (KNT_{i_i}), and other potential influential factors (X). For the function ($f(.)$) of the concept of KPF the Cobb-Douglas production function is usually adopted.

2.3 Survey Background and Descriptive Analysis

2.3.1 Survey Background

The following analysis applies the KPF concept from Criscuolo et al. (2005) and Wagner (2006) to investigate the role of firms' own R&D and the role of knowledge transfer for firms' innovation activities in China. It does not only attempt to explain whether knowledge and technologies transferred from external players matter in this regard. But it also investigates whether technologies and knowledge transferred from different sources may matter for carrying out different kinds of innovation outcomes. In order to do so, it analyses an original firm-level dataset collected by our own company survey in the PRD in Guangdong from late 2007 to early 2008.[10] Guangdong is well-known for its relatively high innovativeness among all provinces in China. In addition, Guangdong is in a leading position regarding international trade of high-tech products in general, compared to the other Chinese provinces (MOST, 2007).

Our PRD Company Survey was only addressed to firms in the electronics industry. The electronics industry has gained in importance for the Asian NIEs during their developing phase since 1960s (e.g. Hobday, 1995b; Tuan and Ng, 1995). Similarly, it has been of increasing importance for the regional economy in Guangdong since the 1980s. Its gross output value amounted to 41% of all industries above a designated size in Guangdong in 2006 (GPBS, 2007).[11] Our survey questionnaires were sent to 400 electronics firms randomly selected from the comprehensive company catalogue 'Guangdong Electronics 2007'. Among them, 222 questionnaires were completed and returned.[12]

2.3.2 Descriptive Analysis

Based on the OSLO Manual, the PRD Company Survey defined innovative firms as those which introduce new or significantly improved products into markets or implement new or significantly improved processes, organisational modes and market

[10] About 80% of the GDP in Guangdong was carried out directly in the PRD in 2006. 2,620 billion RMB (328 billion USD) were produced domestically in Guangdong in 2006 (GPBS, 2007). RMB is an abbreviation for the Chinese currency 'Renminbi', while USD refers to US Dollar.

[11] Gross output value of industry above a designated size consists of the output value of 'all state-owned enterprises' and that of 'non-state-owned enterprises with annual business revenue of over 5 million RMB'. In 2006, the gross output value of industry above a designated size accounted for about 87% of the gross output value of industry for all enterprises (GPBS, 2007).

[12] Survey questions analysed in this chapter are summarised in Table 2.A.1 in the appendix (Section 2.A). To enhance firms' understanding of the survey questions and reduce time which they need to spend on completing the questionnaires, I translated the survey questions into Chinese. Our cooperation partner at the Sun Yat-Sen University, Prof. Li Xun and his research team, communicated with firms for the survey and conducted the follow-up work in Chinese as well. Before the local research team started to conduct the survey, two colleagues from University of Hannover and I gave a two-day training course to the local team members. We gave the training course to help the local research team understand our motives, research background and research goals of the survey on the one hand. On the other hand through the training course we were able to further clarify language-related issues and to adapt some wording of the survey questions to the local style for being more easily understandable. Further improvement was made based on results of the pilot tests on a small number of firms. For the innovation-related part of the survey questionnaire we started with a general question regarding firms' current business strategy, whether they carried out innovation activities and what types of innovation activities they carried out, while innovation was defined as in Oslo Manual (OECD, 2005). Later we asked firms to indicate more exactly what kinds of innovation outputs they realised, answers of which were used as dependent variables of the regressions in this chapter. As quality control we excluded firms from the regression analysis if they indicated at the beginning that they did not carry out innovation activities in general as defined in Oslo Manual (OECD, 2005) or they did not carry out product and/or process innovation activities but indicated later that they realised product- and/or process-related innovation outputs. Excluding firms like these helps ensure the consistency of firms' answers to the innovation-related questions.

strategies in their business operations (OECD, 2005). Survey results show that there are 158 innovative firms among 221 responding companies in total (71%).[13] These innovative firms were further asked to answer the other innovation-related questions.

In order to carry out innovation activities, survey results show that innovative firms in the PRD do not only engage in own R&D activities but they also acquire knowledge and technologies from other innovators to expand their innovation capabilities. On average, they invested about 8% of their whole product sales in 2006 in their R&D activities, reflecting a relatively high innovation incentive among the responding companies.[14] However, it is worth noting that four of the innovative firms did not spend any dollar on their R&D activities at all, suggesting their reliance on knowledge and technologies sourced from elsewhere to support their innovation activities. In the survey, seven different sources of knowledge and technologies were considered: 'OEM customers (oem)', 'suppliers or non-OEM customers (supnoem)', 'companies from the same industry (compet)', 'universities or research institutes (uni)', 'fairs or technical markets (mkt)', 'parent company, affiliated companies or joint ventures (group)', and 'hiring highly-qualified workers (pers)'.[15] While about 69% of the innovative firms in the PRD rely on hiring highly-qualified workers to extend their innovation capabilities, only 40% of them make use of universities or research institutes

[13] One of the 222 PRD firms did not answer the question which asked firms to specify whether they carry out innovation activities. The definition of innovation based on the OSLO Manual was explained in detail in the appendix of the survey questionnaire. Firms were reminded to read the definition of innovation before they answered the innovation-related questions in the survey.

[14] We obtained valid information on firm-specific R&D-to-sales ratio in 2006 from 142 innovative firms. The first, second and third quantile value of R&D-to-sales ratio among innovative firms in the PRD in 2006 was 3%, 6% and 10%, respectively. The maximum of the R&D-to-sales ratio amounted to 60%.

[15] The CIS (Community Innovation Survey) questionnaire and the questionnaire of Hannover Firm Panel were used as references to determine the alternative sources to be considered in this question of our survey. Data of these two surveys were analysed in our base literature – Criscuolo et al. (2005) and Wagner (2006). Criscuolo et al. (2005) summarised the information sources based on the CIS-3 questionnaire as follows: internal information from self, internal information from group, vertical information from suppliers and customers, information from competitors, commercial information, free information, regulatory information, information from universities, and information from government. Wagner (2006) focused on firms' cooperation partners as sources and summarised them as follows: other firms from enterprise, customers, suppliers, competitors, service providers, and universities/other research institutes. The information sources considered in our survey shared a high degree of similarity with the spectrum of information sources considered in Criscuolo et al. (2005) and Wagner (2006), while there were still some differences in order to take into account the specific features of the economic developing process in East Asia. The high relevance of OEM customers and highly qualified workers as knowledge sources for innovation of firms in the Asian NIEs (e.g. Hobday, 1995a & 1995b) induced us to separate the OEM customers as information sources from the other customers and suppliers on the one hand and hiring qualified workers from other stakeholders from the same enterprise group on the other hand. To ensure the completeness of the information sources considered, we added in the alternative 'other sources' into the corresponding question. Only few firms (17 firms in total) indeed applied information sources other than the specified ones and the information sources applied are at least a little important for them (i.e., at least with the importance level of 4).

as their knowledge sources. The shares of innovative firms using the other five knowledge sources lie between these two extremes. Among these five knowledge sources, firms especially rely on their parent company, affiliated companies or joint ventures (56%) to source innovation-related information and technologies.[16]

Although a great part of firms simultaneously makes use of several knowledge sources specified in the survey for their innovation activities, it does not necessarily mean that innovative firms may perceive same importance among the knowledge sources used by them. In the survey, innovative firms were asked to assess the importance of knowledge sources used by them, using a five-level Likert scale with '1' indicating very important and '5' not important.[17] Based on firms' responses, pairwise Wilcoxon Signed Rank Tests (WSRTs) were applied to clarify the relative importance between different knowledge sources perceived by firms.[18] Results show that innovative firms perceive hiring qualified workers as the most important source for them to obtain innovation-related information and technologies. They tend to evaluate knowledge sources such as 'parent company, affiliated companies or joint ventures', 'OEM customers', 'fairs and technical markets' and 'suppliers or non-OEM customers' with the same importance but they are less important than sourcing knowledge through hiring qualified workers. Lastly, they tend to evaluate the other two knowledge sources such as 'companies from the same industry' and 'universities or research institutes' with the lowest importance in general.

Innovative firms in the PRD carry out different kinds of innovation outcomes based on their investments in own R&D activities as well as in sourcing knowledge and technologies from other more experienced innovators. About 92% of innovative firms introduce products with new or improved functions into markets.[19] A smaller share of innovative firms (81%) implements new or improved production processes.[20] Irrespective of innovative products or innovative processes, most of the innovative firms tend to make improvement in the existing products or ongoing production

[16] We obtained in total 152 (153) valid responses to the sub-questions regarding 'OEM customers', 'suppliers or non-OEM customers', 'universities or research institutes' and 'hiring highly-qualified workers' ('companies from the same industry', 'fairs or technical markets' and 'parent company, affiliated companies and joint ventures') as knowledge sources, respectively.

[17] Company shares by importance of different knowledge sources are summarised in Table 2.A.2 in Section 2.A.

[18] Results of WSRTs are not presented in tables but directly interpreted here to save space. Results in tables are available upon request.

[19] We obtained in total 134 valid responses to the question regarding innovative products.

[20] We obtained in total 139 valid responses to the question regarding innovative processes.

processes instead of to develop totally new products or new production processes.[21] In addition to introducing innovative products and implementing innovative processes, about 77% of innovative firms in the PRD also apply for patents to protect their products from illegal imitation.[22] And 37% of innovative firms realise more than half of their total product sales with selling innovative products.[23]

In summary, how firms in the PRD in China innovate does not seem to be completely the same as firms in the Asian NIEs did decades ago when they just started their industrial upgrading processes. On the one hand, innovative firms in the PRD are found to rely on sourcing technologies and knowledge especially from their parent company, affiliated companies, joint ventures or OEM customers to extend their innovation capabilities just like that done by companies in the Asian NIEs. Most of them are found to implement new or improved production processes over time as their counterparts in the Asian NIEs.

On the other hand, some differences in innovation between firms in the PRD and their counterparts in the Asian NIEs can also be identified. First, firms in the PRD evaluated hiring qualified workers as the most important knowledge source for innovation. Qualified workers considered in the survey were not restricted to those educated abroad, while human capital trained abroad was of especially high relevance for innovation of firms in Asian NIEs. That also locally well-educated workers were considered to be transmitters transferring knowledge from academia to industry may be attributable to the higher education reform towards a system of mass higher education since the late 1990s. This gives some support for the relevance of universities for firms' innovation activities in China. This finding also suggests, however, a seemly more important role of universities as training basis instead of as potential innovation cooperation partners for firms. As the second difference, some of innovative firms in the PRD started to invest a lot in their own R&D activities. Thirdly, relatively more PRD firms introduce innovative products into markets than implementing innovative processes. The last two features were not found at the beginning of the industrial upgrading in the Asian NIEs, either. They were firstly found after the firms in the Asian NIEs already gained some more innovation capabilities and experiences. The

[21] About 41% of 123 firms with innovative products develop totally new products while 69% of them make significant improvements in the existing products. About 28% of 113 firms with innovative processes implement totally new production processes, while 78% of them implement improved ones.
[22] We obtained in total 145 valid responses to the question regarding patenting.
[23] We obtained in total 130 valid responses to the question regarding innovation sales.

observation of these three different features in China in 2007 suggests that the problem of lacking innovation capabilities and financial capital for innovation may not be so severe anymore.

2.4 Econometric Analysis

2.4.1 Estimation Issues

We apply econometric techniques based on the framework of knowledge production function to investigate the relations between different innovation inputs and different kinds of innovation outcomes realised by the electronics firms in the PRD in China in more detail. In total, we consider four different innovation outcomes: innovative products, innovative processes, sales of innovation products and patenting activities. Reasons for focusing on these four different innovation outcomes are twofold. On the one hand, these innovation outcomes were considered in Criscuolo et al. (2005) and/or in Wagner (2006) (Section 2.2.2) as well. Focusing on the same innovation outcomes makes a comparison between our findings and their findings more possible. On the other hand, we expect against the innovation experience of firms in the Asian NIEs that, due to different characteristics of various innovation outcomes, innovation inputs may matter to different degrees for firms to realise various innovation outcomes.

More concretely, we expect, firstly, that firms may rely more on own R&D activities to carry out innovative products and to create qualified knowledge and technologies for patenting, for which they may not easily obtain support from other knowledge sources such as their OEM customers as suggested by the empirical literature in the Asian NIEs. In contrast, we expect that companies may rely more on sourcing technologies and knowledge from their OEM customers or from their parent company, affiliated companies or joint ventures to improve their production efficiency. The low relevance of sourcing from OEM customers for carrying out innovative products may be further reflected in the low relevance of this knowledge source for higher innovation sales. Secondly, firms may rely strongly on visiting fairs and technical markets to obtain up-to-date information about market needs which is expected to be more relevant for carrying out innovative products than innovative processes. For carrying out innovation processes, firm-specific information is more likely required. Last but not least, firms may make use of the expertise of universities and research institutes to gain especially advanced new knowledge for creating new technologies which may be qualified enough for patenting. Considering these four different innovation outcomes can thus support us to compare our findings for China with the innovation experience of firms in the Asian NIEs with whom firms in China share some similarity in the economic developing processes.

In order to investigate the role of different innovation inputs for different innovation outcomes, four groups of estimation models with ‘innovative products’, ‘innovative processes’, ‘innovation sales’, and ‘patenting’ as individual outcome variable are estimated, respectively. These four outcomes are codified into four binary variables with ‘1’ representing the corresponding firm ‘introduces products with totally new or improved functions into markets (*product*)’, ‘implements totally new or improved production methods (*proccess*)’, ‘realises above-average innovation sales (*innosales*)’ [24], and ‘applies for patents to protect their products from illegal imitation (*patent*)’, respectively.[25] Each group consists of one baseline KPF model and three

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[24] Through the PRD Company Survey 2007 we did not obtain directly information on innovation sales in absolute term. Instead, we obtained categorical information on firms’ sales (six categories: ‘❑<1 Mio’, ‘1≤❑<5 Mio’. ‘5≤❑<10 Mio’, ‘10≤❑<50 Mio’, ‘50≤❑<100 Mio’ and ‘❑≥100 Mio’) and on share of sales realised with innovative products (five categories: ‘☐=0%’, ‘0<☐≤10%’, ‘10<☐≤25%’, ‘25<☐≤50%’ and ‘50<☐≤75%’, ‘75<☐≤100%’). In order to transform the information on innovation sales from the relative term to the absolute term, we make use of the average value of the upper bound and the lower bound of each available category with respect to sales and share of sales with innovative products. However, the lower bound of the 1st-category sales and the upper bound of the 6th-category sales were not specified in the survey. The former one is set to be 0 for this study. The latter one is determined as follows. The upper bounds of the lower five categories are divided by the number of employees of the corresponding firm. The average of the calculated sales per capita is then used to be multiplied by the maximum of the number of employees to obtain the upper bound of the 6th-category sales. The innovation sales of firm *i* with the sales in the ‘m’ category and share of sales with innovative products in the ‘n’ category, for example, is calculated by multiplying the average value of the ‘m’-category sales with the average value of the ‘n’-category share of sales with innovative products. After that, innovation sales are transformed into their log form. The mean of the innovation sales in log is used as the critical value to separate companies into those with under-average innovation sales and with above-average innovation sales

[25] The four innovation outcomes, except for the variable of innovation sales, are codified as dummy dependent variables, following Criscuolo et al. (2005) and Wagner (2006). As regards the variables of product and process innovation, Criscuolo et al. (2005) considered ‘whether firms reported any product or process innovation or not’, while Wagner (2006) considered ‘whether firms installed any new production process or not’. In our analysis, data allowed us to separate product innovation from process innovation; thus, we considered ‘whether firms introduce innovative products or not’ and ‘whether firms implement innovative production methods or not’ as dummy outcome variables, respectively. As regards the variable of firms’ patenting activities, Criscuolo et al. (2005) considered ‘whether firms applied for new patents or used existing patents for protection or not’, while Wagner (2006) defined the variable in a more restrictive way, namely ‘whether firms applied at least one patent in the survey year’. In our case we defined the variable of patent in a similar way, i.e. ‘whether firms apply for patents for protecting their products from product piracy’. As regards the variable of innovation sales, limited data availability (see Footnote 24) makes it impossible for us to follow the corresponding definition of Criscuolo et al. (2005) and Wagner (2006). Criscuolo et al. (2005) considered the value of innovation sales directly and Wagner (2006) the share of sales realised with new products. Despite the data availability problem, in order to at least gain some insights into different roles of various innovation inputs for firms’ innovation sales, we decide to define our variable of innovation sales, based on the categorical responses of firms, as a dummy outcome variable as well for further analysis (see Footnote 24).

extended models. Due to the binary characteristics of the outcome variables, the baseline KPF models as probit regressions are estimated:

$$\Pr(Y = 1 \mid X) = \Phi(X'\beta) \qquad (2.4)$$ [26]

where Y refers to the four innovation outcomes considered separately. X is a vector of explanatory variables and β is a vector of parameters reflecting the effects of X on the probability.[27] $\Phi(.)$ denotes a standard normal distribution. The probit models are estimated with robust standard errors.[28]

All four baseline KPF models consider the following set of explanatory variables:

$$X_i = (X_i^{rd}, X_i^{tt}, X_i^{fc}). \qquad (2.5)$$

These models consider first of all firms' own R&D engagement (X_i^{rd}) measured in their R&D expenditure in log (*lnexprdtr*$_i$)[29] as other KPF-based literature due to its substantial role for firms' innovation success as being assumed from the start of the development of the KPF concept (Griliches, 1979) and being further substantiated over time by related empirical findings (see Section 2.2.2). In addition to firms' own R&D engagement these models, more importantly, consider firms' application of knowledge and technology transferred from different sources (X_i^{tt}) as innovation inputs. In total, the models consider seven different knowledge sources: firms' OEM customers (*oem_dm*$_i$), their suppliers or non-OEM customers (*supnoem_dm*$_i$), companies from the same industry (*compet_dm*$_i$), universities or research institutes (*uni_dm*$_i$), exhibitions or technique markets (*mkt_dm*$_i$), parent company or other affiliated companies (*group_dm*$_i$), and hiring qualified workers (*pers_dm*$_i$). The data for these variables were obtained by a corresponding question of our survey as analysed in Section 2.3.2. The knowledge sources considered in our survey were comparable with the sources

[26] The observation subscript '*i*' is omitted here. See Greene (2003) p665-666 for more information.

[27] Because probit models are non-linear models, estimated coefficients (β) are not exactly equal to the marginal effects of the explanatory variables but they principally provide sufficient information on the directions of the effects of *X* on the outcome probability.

[28] More concretely, the Stata module 'probit' with variance type 'robust' is used for estimation. See STATA (2005b) p468-482 and STATA (2005c) p493-496 for more information.

[29] Through the PRD Company Survey 2007 we did not obtain directly information on R&D expenditure in absolute term. Instead, we obtained information on R&D-to-sales share in percent and categorical information on companies' sales (six categories, see Footnote 24). We transform the information on R&D-to-sales share to R&D expenditure in absolute term by multiplying the R&D-to-sales share of each firm with the average value of sales of the corresponding sales category. We obtain the upper boundary of the 6^{th}-category sales and the average sales of every sales category in the same way as described in Footnote 24. In order not to lose zero observations on R&D expenditure, we transform R&D expenditure (exprd) before taking logs as suggested by Feldman and Florida (1994) for their analysis based on regional knowledge production function for the US. More precisely, *lnexprdtr* = ln(exp(1)*(1+exprd)). In this dissertation the abbreviation 'log' is synonym for the abbreviation 'ln'. Both mean the natural logarithm.

considered in Criscuolo et al. (2005) and Wagner (2006), taking additionally the specific features of economic development process in East Asia into account (see Footnote 15). All these variables are codified in dummies and are equal to 1 if companies apply the corresponding knowledge sources.[30]

Moreover, the baseline models take several firm characteristics into account to control for firm heterogeneity with respect to carrying out innovation activities (X_i^{fc}). Firm characteristics considered in this study are firm size (e.g. Criscuolo et al., 2005; Wagner, 2006) measured by the number of total employees in log ($lnsize_i$), firm age (e.g. Jefferson et al., 2006; Wagner, 2006; Girma et al., 2009) (age_i)[31], whether they are exporters or not ($exporter_i$) and their ownership structure (Markusen, 2002; Criscuolo et al., 2005; Hu et al., 2005; Jefferson et al., 2006; Wagner et al. 2006). The ownership structure of firms is considered by using two dummies referring to whether firms are totally foreign-owned companies ($foreignown\_to_i$) or whether they are joint ventures between Chinese and foreign investors ($foreignown\_mi_i$), respectively.[32]

Beyond the baseline models, three model extensions are estimated to investigate the robustness of the core findings. First, potential endogeneity problem regarding companies' R&D expenditure in the baseline models is considered. Based on the concept of KPF, R&D expenditure is needed to produce innovation outcomes; however, it is also possible that the amounts of R&D expenditure are determined by firms' prior success in carrying out innovation outcomes. To deal with this issue, valid instrumental variables are identified and they are further used to instrument companies' R&D expenditure for estimation.[33]

Secondly, importance measures regarding the knowledge sources used by firms are considered in the extended models to substitute for the original source dummies

[30] Codifying the variables in this way is consistent with Wagner (2006). Criscuolo et al. (2005) used the categorical data they have to assign one of the following four values '0, 1/3, 2/3, 1' to the corresponding variable for each information source. A strong underlying assumption for codifying variables in this way is that Criscuolo et al. (2005) assumed that the marginal effect of category change on innovation outcomes is constant, irrespective of the starting position of change. In our survey we have categorical information regarding the importance of different knowledge sources for firms as well. Different from Criscuolo et al. (2005), we use this additional information by codifying them into two dummies for each knowledge source to check the robustness of results, and thus no such a strong assumption is made in our case. See below for more information.

[31] Company age is calculated in the following way: 2007- 'start year of firms' operations in the PRD'.

[32] Description of variables and some basic descriptive statistics are summarised in Table 2.A.3 in the appendix (Section 2.A).

[33] See Section 2.4.2.2 for more information.

(whether certain knowledge sources are used or not) in the baseline models.[34] We use such importance measures to proxy the usage intensity of different knowledge sources used by innovative firms in the PRD. Given that technologies and know-how transferred from some knowledge sources indeed matter as innovation inputs for carrying out certain innovation outcomes, the probability of carrying out such innovation outcomes is expected to be higher, when these knowledge sources are used more intensively. The importance of each of the seven knowledge sources perceived by firms is codified in two dummies: whether knowledge sources are perceived as a little important or normally important (oem_md_i, $supnoem\_md_i$, $compet\_md_i$, uni_md_i, mkt_md_i, $group\_md_i$, $pers\_md_i$) and whether knowledge sources are perceived as important or very important (oem_st_i, $supnoem\_st_i$, $compet\_st_i$, uni_st_i, mkt_st_i, $group\_st_i$, $pers\_st_i$).[35]

As mentioned above, responding firms in the PRD Company Survey were separated into two groups according to whether they carry out innovation outcomes (innovative firms) or not (non-innovative firms).[36] The estimations from the baseline models and the first two extended models rely solely on the innovation-related data which we obtained among all innovative firms from the PRD Company Survey. Innovation-related data among non-innovative firms were not available, although it is possible that some firms indeed made some innovation efforts but were classified as non-innovative firms because they do not yet carry out any innovation outcomes. If there are indeed such cases, the estimations till now need to be interpreted with more caution. In other words, they may only relate innovation inputs to innovation outcomes among firms which are successful in carrying out innovation outcomes and, thus, overestimate the innovation productivity in general. To cope with this issue and to enable a more generalised interpretation of the estimation results, a second probit equation is considered, in addition to the baseline KPF model, in the third extended

[34] Criscuolo et al. (2005) also utilised the categorical data they have while investigating relevance of different information sources for firms' various innovation success (See Footnote 30.). Different from Criscuolo et al. (2005), we use the data we have and construct for each knowledge source two dummy variables, representing whether firms perceive the knowledge source of interest as moderately important or strongly important, respectively.

[35] The abbreviation 'md' ('st') here means 'moderately' ('strongly') important. The corresponding survey question asked firms to indicate the importance of knowledge sources used by them, using a 5-level Likert scale with the value '1' to '5' representing 'very important', 'important', 'of normal importance', 'a little important', and 'not important', respectively (see Section 2.3.2).

[36] Innovative firms refer to firms which introduce new or significantly improved products into markets or/and implement new or significantly improved processes, organisational modes and market strategies (OECD, 2005).

model construction. This second probit equation regresses 'whether firms are innovative firms or not (*inno*$_i$)', with '1' referring to firms carried out innovation outcomes and '0' not, on several different innovation determinants.

The choice of innovation determinants is supported by the findings of related innovation and growth literature (e.g. Kamien and Schwartz, 1975; Aghion and Howitt, 1998; Aghion et al., 2005; Moreno et al., 2005; Aghion and Howitt, 2009; Scott, 2009): firm size in log (*lnsize*$_i$), competition intensity (*mktcompet*$_i$) and whether firms are manufacturing firms or not (*manuf*$_i$). The competition intensity faced by firms is further classified, due to its ordinal characteristics, into two dummy variables: facing moderately (strongly) increasing competition pressure or not (*mktcompet_md*$_i$ *& mktcompet_st*$_i$). While the size variable is considered in the baseline model as well, the variables '*mktcompet_md*', '*mktcompet_st*' and '*manuf*' are taken as exclusive regressors which are expected to strongly affect firms' innovation success in general but not determine their success in realising a specific type of innovation outcomes. Reasons for their exclusiveness are as follows. Competition is supposed to, as argued by Aghion and Howitt. (1998 & 2009), positively drive firms to innovate if firms are moving closer to the technology frontier. Chinese firms may usually not be recognised as firms with high-tech standards. But our analysis focuses on firms from the electronics industry and the Chinese electronics firms, especially those from the PRD, have been playing a more and more important role over time as high-tech electronics producers for the world market (China Daily, 2011). The increasingly severe competition of the electronics industry worldwide perceived by the electronics firms in the PRD is thus expected to act like a push factor strongly driving their decisiveness in innovation engagement to come out with certain innovation outcomes at the end. However, due to strong sectoral dynamics, the high variety of products with different sophistications and the high degree of specialisation of firms in manufacturing (e.g. Ruane and Görg, 2001; Görg and Hanley, 2005), a higher intensity of competition is not expected to determine firms' success in specific type of innovation outcomes directly. Some firms under competition pressure may profit more from a successful product innovation to increase their market share, while others may sustain their high productivity via developing and introducing more advanced production processes.

Similarly, firms engaging in production activities, i.e. firms as manufacturers, are expected to have more direct opportunities to identify where in their business operations exactly a successful innovation is urgently needed and they are more able to test the semi-finished innovations realised in practice for further improvement. Thus, firms with production activities are expected to be more able to succeed in innovation compared to those not engaging in production activities. However, again due to the specific features of the electronics industry as mentioned above and a potentially larger spectrum which firms with production activities may have for deciding on the area where innovation indeed needs to be carried out, it is less likely that whether firms are manufacturers or not may directly determine whether they are more successful in carrying out a specific type of innovation outcomes. This second probit equation is estimated simultaneously with the baseline KPF model for each of the four innovation outcomes by using a full-information maximum likelihood method.[37]

2.4.2 Estimation Results

2.4.2.1 Results of Baseline KPF Models

Results of estimated coefficients based on the baseline models are shown in Table 2.1, with column (1), (2), (3), and (4) for the baseline model with innovative products, innovative processes, innovation sales, and patenting as dependent variable, respectively. It is worth noting that the estimation results of coefficients in probit models give information on in which directions the independent variables may significantly affect the probability of having innovation outcomes considered equal to 1. The estimated coefficients should, however, not be directly interpreted as marginal effects.[38] All four baseline models are well specified, with the null hypothesis that all regression coefficients considered in the models are equal to zero being rejected at 1% significance level based on the corresponding Wald Chi-squared tests.

The estimation results support our expectation that firms' own R&D engagement and knowledge obtained from diverse sources matter for realising different innovation outcomes to various degrees. Although descriptive analysis above showed that most of the innovative firms in the PRD engage in own R&D activities, such R&D engagement

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[37] For estimation the STATA module 'cmp', referring to 'conditional (recursive) mixed processes' was used. The module 'cmp' estimates (recursive) equation systems by using maximum likelihood estimation procedures directly (Roodman, 2009).

[38] In order to calculate marginal effects in probit models, reference points should be fixed. Normally, the mean values of the explanatory variables are selected to fix the reference point. In our cases, especially the cases with innovative products as innovation outcomes, such a reference firm may already have R&D expenditure at a quite high level, crowding out the importance of knowledge transferred from other sources as inputs for innovation. Therefore we prefer to analyse the results of estimated coefficients here to clarify the general importance of different innovation inputs for different innovation outcomes carried out by innovative firms in the PRD. Estimated marginal effects based on the baseline models are reported in Table 2.A.5 in the Section 2.A.

is not found to matter for carrying out all kinds of their innovation outcomes but especially matter for carrying out those innovation outcomes for which firms in the PRD hardly obtain technical supports from other knowledge sources especially OEM customers. As shown in Table 2.1, the higher the R&D expenditure, the higher the probability that firms may introduce innovative products into markets and they may be capable of carrying out new knowledge sufficiently qualified for patenting. The positive role of R&D expenditure for developing innovative products makes it also more possible that firms with higher R&D expenditure may realise above-average innovation sales. In contrast, R&D expenditure is not found to be significantly relevant for firms to carry out innovative processes successfully.

The finding of different roles of R&D expenditure for realising various types of innovation is consistent with the findings from Criscuolo et al. (2005) and Wagner (2006) for UK and Germany, respectively. Criscuolo et al. (2005) considered R&D personnel instead of R&D expenditure and found a significantly positive role of R&D engagement of firms for their success in innovation sales and patenting activities for protection in most of the estimation models specified. The magnitudes of such positive effects were found to be larger for innovation sales and smaller for patenting that is in line with our findings. As to product innovation and process innovation, Criscuolo et al. (2005) did not differentiate these two from each other and found a generally significantly and positive role of firms' R&D engagement for their success in product or process innovation. Instead, Wagner (2006) investigated the role of R&D engagement of firms, measured in relative size of R&D employment, for new process introduced for production directly. He found that when taking into account other potential knowledge sources as innovation inputs, firms' R&D engagement becomes insignificant for their success in process innovation. The last finding, together with the case studies of Hobday (1995a & 1995b) on innovation activities of firms in the Asian NIEs in the 1990s (see Section 2.2.1), gives some support for our argument specified above that firms' own R&D engagement may play a more dominant role for their innovation success if less support they may expect to obtain from crucial knowledge sources such as OEM customers, with whom firms in the PRD have long-term business relationships in general.

In order to carry out innovative processes to improve production efficiency, innovative firms in the PRD are found to rely strongly on the technologies and knowledge transferred from their OEM customers. On the one hand, long-term business experiences between firms in the PRD and their OEM customers make it easier for them to obtain right technologies and know-how which indeed satisfy their technical needs from their OEM customers.[39] On the other hand, helping firms in the PRD to improve their production efficiency is more consistent with OEM customers' own business strategies focusing on sustaining price competitiveness in the markets. In contrast, OEM customers are expected to be reluctant to transfer technologies and know-how to firms in the PRD to help them develop innovative products or to create new knowledge qualified sufficiently for patenting, because in this way they may help firms in the PRD to become their potential competitors in the future. As suggested in the studies in the Asian NIEs (e.g. Kim, 1991; Hobday, 1995a & 1995b; Kim and Lee, 2002), OEM customers were indeed one of the most substantial knowledge sources for firms in the Asian NIEs. Assumed that OEM customers should play a similar role for the innovative activities of firms in the PRD in general, the finding of a low relevance of OEM customers as knowledge sources for them to carry out innovative products, to realise high innovation sales and to apply for patents is consistent with our argument above that firms which aims at carrying out these three innovative outcomes may need to rely more on own R&D activities.

In addition to own R&D engagement, innovative firms in the PRD which aim to develop innovative products, to realise high innovation sales and to create new knowledge for patenting may try to search for knowledge sources other than OEM customers from which they can obtain technologies and knowledge they need for innovation. In case of developing innovative products, 'fairs or technical markets' and 'parent company, affiliated companies and joint venture companies' are found to be the two knowledge sources which significantly matter. Technical markets may provide them up-to-date information about market needs or about newly available technologies, both of which are relevant for firms to develop innovative products. Parent company, affiliated companies and joint venture companies may act in some situations like OEM customers and focus more strongly on price competitiveness. However, different from the OEM customers, companies from the same enterprise group tend to follow the same goal to maximise the profit of the whole enterprise group. Therefore, companies from the same enterprise group to which innovative firms in the PRD belong may provide them more know-how and technologies relevant for developing innovative products.

[39] The OEM business mode has been dominantly applied among companies in the PRD over the whole developing processes since the late 1970s (FHKI, 2003).

That markets and companies from the same enterprise group matter as relevant knowledge sources for firms' success in product innovation finds some support from Criscuolo et al. (2005). They found that for the success of UK firms in any product and process innovation commercial information, e.g. commercial laboratories, and free information, e.g. fairs and exhibitions, on the one hand and information from companies from the same enterprise group on the other hand play significantly positive roles.[40] It is worth noting, however, that Criscuolo et al. (2005) considered firms' success in product innovation or/and process innovation as an innovation output; and our analysis separates these two types of innovation outcomes from each other. Despites, in line with the finding of Criscuolo et al. (2005) both markets and companies from the same enterprise groups are found to be positively relevant, though not significant, for firms' success in process innovation as well.

Knowledge sources which are advantageous for developing innovative products are expected to be also advantageous for realising higher sales with innovative products. However, the two knowledge sources which are found to matter for carrying out innovative products above are not found to matter for realising higher innovation sales. This suggests, firstly, up-to-date information on market needs and supplies of technologies may be advantageous for developing innovative products. But these products need not be indeed well accepted and sold in the markets. Secondly, although companies from the same group may help innovative firms in the PRD to produce innovative products, these innovative products may rather be used as intermediate goods for production in some other companies from the same enterprise group instead of being sold directly to the markets. In contrast, to realise higher innovation sales, three other knowledge sources are found to be of higher importance: suppliers or non-OEM customers, companies from the same industry, and universities or research institutes. The finding that suppliers and non-OEM customers matter significantly and positively in this regard is consistent with Criscuolo et al. (2005) and Wagner (2006). The other two knowledge sources which are found to be significantly and positively relevant as well finds only some support from Criscuolo et al. (2005) but not from Wagner (2006). Wagner (2006) showed that competitors and universities as R&D cooperation partners

[40] In addition, Criscuolo et al. (2005) found that information obtained from vertical sources matters for firms' success in product and/or process innovation as well, while sourcing information from competitors rather plays a negative role in this regard. These two findings are consistent with our regression results with respect to suppliers and non-OEM customers as vertical information source and firms from the same industry as competitors. The corresponding coefficients share the same signs with Criscuolo et al. (2005), though they are not significant for the China case.

rather affect negatively, though not always significantly, innovation sales of firms in Germany.

Taking the finding of insignificant roles of these three sources for innovative firms in the PRD to develop innovative products into account, knowledge which innovative companies obtain from these sources may rather tend to be used to increase the attractiveness and acceptance of their products among customers than to improve the products technically. For example, firms may learn from the marketing strategies of their competitors or from the business research of universities how they can more efficiently market and sell their products. The focus on rather non-technical than technical knowledge inputs from competitors and universities may be one of the reasons why these two knowledge sources matter for the PRD firms' innovation sales but the same sources seem not to play a comparable role when considering them as R&D cooperation partners for the German case in Wagner (2006).

Universities and research institutes, however, may not only provide results of business research to help innovative firms to better market and sell their products. As suggested by the positive finding of this knowledge source for patenting in Table 2.1, they may also provide innovation-related technologies and knowledge which can be used by innovative firms in the PRD as innovation inputs to produce new knowledge qualified enough for patenting. Such finding signifies a significantly relevant role of universities as knowledge sources for firms' patenting activities, although descriptive statistics in Section 2.3.2 showed that actually only few innovative firms in the PRD indeed recognised the relevance of universities as such for their innovation activities. That universities are crucial knowledge sources for supporting firms' patenting activities was also evidenced by the regression results in Criscuolo et al. (2005) for UK and in Wagner (2006) for Germany.

In addition to universities, fairs or technical markets seem to provide innovation-related technologies to support innovative firms' patenting activities in the PRD as well. However, it is worth noting that the variable 'patenting' was derived from a question which asked innovative companies, whether they apply for patents to protect their products from piracy. Based on this question, it is possible that especially those firms which trust formal institutions such as transaction rules in the technical markets tend to utilise the other formal institutions such as patent laws to protect their products. Therefore, the positive relationship found between market as knowledge source and patenting may be partially due to the preference of such firms for making use of formal institutional rules for innovation. Nevertheless, Criscuolo et al. (2005) which considered a comparable patenting variable also found that information obtained from market-related sources such as commercial information and free information affects significantly and positively UK firms' patenting activities.

In contrast to these two knowledge sources, sourcing from suppliers or non-OEM customers is found to be significantly and negatively relevant for the patenting activities of the innovative firms in the PRD. Such negative impacts were also found in Criscuolo et al. (2005). Suppliers, especially, may provide more advanced products which can be further used as inputs into innovation activities of the innovative firms in the PRD. However, they may tend to provide only those products which are already well-patented to protect their products from being imitated by innovative firms in the PRD.

Estimation results of the baseline models also suggest that different firm characteristics, especially how innovative firms are involved in the global affairs, may matter for their knowledge production behaviour. Firms' different types of global engagement are found to be related to their success in various innovation outcomes to different degrees. Such finding is, however, different from Criscuolo et al. (2005) and Wagner (2006). They found that firms' export activities and their role as multinationals affect positively their innovation success across all types of innovation outcomes they considered for UK and for Germany, respectively. Different comparative advantages of firms in the PRD from their counterparts in UK and in Germany may be one of the reasons resulting in such different findings. In our case, we find, firstly, that exporting firms are more capable of realising higher innovative sales. But they need not be more capable of developing innovative products. This seems to suggest that exporting firms may profit more from their better established distribution networks worldwide than from obtaining access to up-to-date information about customer needs and technologies supplied in global technical markets. Secondly, innovative firms which are partially owned by foreign investors are found to be less capable of producing new knowledge qualified enough for patenting. Foreign investors may be reluctant, due to the control difficulty based on the partial ownership and the relatively deficient intellectual property right regime in China, to transfer more advanced but also more sensitive knowledge into the invested firms on site which firms in the PRD may need as innovation inputs for producing new knowledge for patenting. In contrast, innovative firms which are totally owned by foreign investors tend to be more capable of patenting.

The estimated coefficient regarding patenting behaviour of totally foreign-owned firms is found to be positive, though not significant. Such totally foreign-owned firms are also found to be significantly more capable of carrying out innovative processes.

	product (1)	proccess (2)	innosales (3)	patent (4)
lnexprdtr	0.822*	-0.074	1.952***	0.232*
	(0.423)	(0.148)	(0.414)	(0.128)
oem_dm	-1.314**	0.846**	-0.997**	-0.156
	(0.537)	(0.373)	(0.418)	(0.380)
supnoem_dm	0.632	0.286	0.895**	-0.862**
	(0.391)	(0.409)	(0.449)	(0.398)
compet_dm	-0.348	-0.590	0.890*	-0.274
	(0.359)	(0.384)	(0.475)	(0.352)
uni_dm	0.496	-0.003	0.881***	0.615*
	(0.406)	(0.374)	(0.329)	(0.357)
mkt_dm	0.905**	0.549	-0.541	0.868**
	(0.368)	(0.347)	(0.435)	(0.367)
group_dm	0.606*	0.232	-1.097***	0.466
	(0.363)	(0.337)	(0.393)	(0.325)
pers_dm	-0.658	-0.344	-0.656*	0.081
	(0.436)	(0.355)	(0.397)	(0.323)
lnsize	-0.033	0.151	0.036	-0.045
	(0.231)	(0.169)	(0.175)	(0.163)
age	0.031	0.034	0.033	0.027
	(0.033)	(0.023)	(0.042)	(0.031)
exporter	-0.485	-0.225	0.766*	-0.112
	(0.525)	(0.408)	(0.428)	(0.365)
foreignown_to	0.383	0.915**	-0.311	0.083
	(0.488)	(0.402)	(0.430)	(0.344)
foreignown_mi	-0.883	0.371	0.188	-1.525***
	(0.733)	(0.584)	(0.534)	(0.416)
_cons	0.616	-0.340	-4.193***	0.301
	(1.306)	(0.709)	(0.976)	(0.630)
Obs.	117	120	116	122
Wald Chi2	27.72***	28.41***	50.15***	30.98***
Pseudo R2	0.299	0.225	0.554	0.224

Notes: ***/**/* refer to 1%/5%/10% significance level. Robust standard errors are presented in parentheses.

Table 2.1 – Estimation Results of the Baseline Firm-level Knowledge Production Function by Innovation Outcome (Estimated Coefficients of the Baseline Models)

In summary, our core findings on the role of firms' R&D engagement and the relevance of different knowledge sources for firms' success in various types of innovation based on the baseline model estimation are consistent with the findings of Criscuolo et al. (2005) for UK to great extent but less with Wagner (2006) for Germany. One crucial difference worth being noted is the consideration of OEM customers as potential knowledge sources for firms' innovation success in the PRD, while such source was not explicitly considered in the other two studies. The evidenced crucial role of OEM customers as knowledge sources for especially PRD firms' success in process innovation is consistent with the results of case studies in East Asia (e.g. Hobday, 1995a & 1995b). This substantiates the importance of including such region-specific knowledge source in our innovation analysis for the PRD.

2.4.2.2 Results of Extended Models

As mentioned in Section 2.4.1, three extended models for all four innovation outcomes are considered in this study. First, we aim to cope with the potential endogeneity problem of R&D expenditure by using instrumental variable estimation techniques. We use the following two variables as potential instruments for R&D expenditure: *predict* and *careerceo*.

The first variable ($predict_i$) is a binary variable with '1' indicating that firms could at least a little bit predict the policy changes over the last five years in China.[41] Since the beginning of the new century, the Chinese government turns to emphasise the importance of innovation and upgrading for sustaining the economic growth in China more strongly than before, focusing especially on encouraging firms to more intensively engage in R&D activities to realise indigenous innovation in the long term. Related financial policy which provides tax preferential treatment to firms doing R&D and improves the financial and banking system in China to reduce the financing difficulty faced by firms has been implemented to motivate firms to invest in R&D activities. Some policy studies in the Asian NIEs suggest positive effects of innovation policies on industrial innovations at home (e.g. Eriksson, 2005). Based on these findings, we expect that innovation policies, together with the related financial policy, in China may also be positively influential for firms' willingness in engaging in R&D activities. Therefore, we expect that firms which can better predict such R&D-friendly policy changes may thus better succeed in innovation through their increasing engagement and investment in own R&D activities but less likely through sourcing innovation inputs from others.

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[41] The variable 'predict' is constructed based on a survey question which asked executives or senior managers of firms to specify how predictable changes of government regulations and policies for their company during the past five years. Here a five-level Likert scale was used with '1' to '5' referring to very predictable, predictable, normally predictable, a little predictable and not predictable, respectively. The variable 'predict' in the regression analysis is set equal to '1' if the corresponding firm gave an answer being smaller or equal to 4 to the survey question. About 78% of firms can at least predict policy changes during the past five years a little bit. See Table 2.A.3 in the appendix for more information.

The second instrumental variable (*careerceo*$_i$) is also a binary variable with '1' indicating that the chief executive officer (CEO) of the firms in the PRD worked in the Chinese state-owned enterprises or in other private companies before they started to work as CEOs in the current firms. Given such work experience, CEOs may bring their well-established personal networks especially with public bureaus into current firms. Such networks may make it easier for current firms to have a better overview of on-going public regulations related to public innovation promotion and to preferential treatment for firms doing R&D. In addition, such networks may grant the current firms an easier access to bank loans for supporting own R&D activities. Thus, we expect that CEOs' prior external working experience may indeed affect firms' success in innovation through especially their extended networks which make it easier for them to obtain financial capital and preferential treatment to support their R&D activities.

We estimate the four instrumental variable probit (iv-probit) models by using Newey's efficient two-step estimator (Newey, 1987), respectively.[42] Each of the iv-probit models consists of the corresponding baseline KPF model and an equation which regresses R&D expenditure on the two abovementioned instruments and on the other exogenous variables specified in the baseline KPF model. We obtain from the first-stage estimations a relatively high F statistics (around 7) and a p-value smaller than 0.01, irrespective of innovation outcomes considered. This implies a relatively high relevance of the instrumental variables used here for instrumenting R&D expenditure.[43] Based on the estimation results of the full models, we apply overidentification tests using Amemiya-Lee-Newey minimum chi-squared statistics to test the validity of instrumental variables (Baum et al., 2003; Baum et al., 2006). Irrespective of innovation outcomes considered, the test results cannot reject the null hypothesis that all instruments are valid. Given the relevance and validity of the instruments used, we apply Wald tests on the correlation parameter between the error term of the baseline probit model considered and the error term of the linear function of R&D expenditure to test whether R&D expenditure is indeed an endogenous variable and instrumental-variable estimation is indeed needed (Wooldridge, 2002). Again, irrespective of innovation outcomes considered, results of Wald tests can not reject the null hypothesis

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[42] More concretely, we apply the STATA module 'ivprobit' here. See STATA (2005a) p517-530 for more information.

[43] F Statistics equal to 10 is often used as a rule of thumb (e.g. Staiger and Stock, 1997; Kilic et al., 2007) to suggest joint significance of instruments. In our case, F Statistics equal to 7 is relatively high but is still smaller than 10. However, limited data availability restricts the use of further variables as exclusive instrument variables.

of zero correlation, suggesting that the potential endogeneity problem of R&D expenditure does not seem to be significant in our cases and our estimation results of the baseline models above stay valid. Table 2.2 summarises the three test results for each iv-probit model estimated.

Innovation outcome considered	product	process	innosales	patent
Number of observations	115	118	114	120
1. F Statistics (Test of joint significance of instruments)	6.91	7.06	6.90	6.75
	(0.000)	(0.000)	(0.000)	(0.000)
2. Amemiya-Lee-Newey minimum chi-squared statistics	0.787	0.379	0.395	2.531
(Test of validity of instruments)	(0.375)	(0.538)	(0.530)	(0.112)
3. Wald test of exogeneity	0.07	2.46	1.14	0.97
	(0.797)	(0.117)	(0.286)	(0.325)
Instrumented: lnexprdtr				
Instruments: predict, careerceo and all other exogenous variables in the baseline models				

Note: p-values are presented in parentheses.

Table 2.2 – Summary of Test Results Based on the Estimation of the Firm-level Knowledge Production Function Using Instrumental Variable Techniques by Innovation Outcome

In the second extended models, the baseline dummy variables representing whether firms source from certain knowledge sources or not are substituted by the importance measures of the corresponding knowledge sources. The importance measures as such are used to proxy the usage intensity of knowledge sources used by the innovative firms in the PRD. Based on the second extended models, in addition to check the result robustness, we aim to test whether the usage of knowledge sources alone matters for innovation or the usage intensity also plays an important role in this regard. Results suggest that the core findings from the estimated baseline models are hardly affected (Table 2.A.4 in Section 2.A).[44] Knowledge sources which were found to matter based on the baseline models stay significantly relevant. In addition, based on the findings of the extended models we apply z-test statistics[45] to test whether usage intensity also matters. Table 2.3 shows the test results. The usage intensity of most of the knowledge sources which were found to be significantly and positively relevant based on the baseline models does not seem to matter. The knowledge source 'technical markets and fairs' is the only one exception. The more intensively firms source from

[44] Table 2.A.4 in Section 2.A presents the estimated coefficients of the extended models and Table 2.A.5 the marginal effects at a selected reference point. See Footnote 38 for additional information.

[45] We used the Stata build-in function 'lincom' to test the difference between the estimated coefficients of knowledge sources with different importance measures. See STATA (2005b) p39-45 for more information.

markets, the higher the probability that they may successfully develop innovative products or may successfully create new knowledge qualified for patenting.[46] Such findings suggest that most of the knowledge sources which were found to be significantly and positively relevant based on the baseline models are crucial sources from which firms may obtain key information for innovation. In these cases, the usage of these knowledge sources alone already matters.

Hypothese (H_a, 1-tailed)	product	process	innosales	patent
	(1)	(2)	(3)	(4)
_b[oem_st]-_b[oem_md]>0	-0.338	0.352	1.053**	-0.287
	(0.748)	(0.521)	(0.627)	(0.555)
_b[supnoem_st]-_b[supnoem_md]>0	1.826**	-0.258	-1.686	-0.489
	(0.806)	(0.756)	(0.734)	(0.627)
_b[compet_st]-_b[compet_md]>0	-1.092	1.761***	-0.310	-0.359
	(0.744)	(0.632)	(0.585)	(0.600)
_b[uni_st]-_b[uni_md]>0	-[a]	0.647	0.112	-0.570
	-[a]	(0.623)	(0.541)	(0.816)
_b[mkt_st]-_b[mkt_md]>0	1.168*	-0.398	1.079**	1.395**
	(0.807)	(0.607)	(0.519)	(0.676)
_b[group_st]-_b[group_md]>0	-[b]	-1.135	1.472**	-[c]
	-[a]	(0.695)	(0.736)	-[c]
_b[pers_st]-_b[pers_md]>0	0.608	1.002**	-0.098	-1.073
	(0.500)	(0.593)	(0.432)	(0.530)

Notes: [a]Not available because Uni_st is dropped due to perfect success prediction. [b]Not available because Group_md is dropped due to its perfect success prediction. [c]Not available because Group_md is dropped due to its perfect success prediction. ***/**/* refer to 1%/5%/10% significance level. Standard errors are presented in parentheses.

Table 2.3 – Summary of Test Results on the Role of Usage Intensity of Knowledge Sources by Innovation Outcome (Based on the Extended Firm-level Knowledge Production Function with Importance Measures of Knowledge Sources)

In contrast, results show that usage intensity of some knowledge sources, which were found to be insignificant for certain innovation outcomes, matters. These knowledge sources are 'suppliers and non-OEM customers' for developing innovative products, 'companies from the same industry' and 'hiring qualified workers' for implementing innovative processes, and 'markets' for realising above-average innovation sales. Alone the usage of these knowledge sources would not matter for carrying out the corresponding innovative outcomes. However, with intensive usage of these sources firms are expected to be more capable of carrying out the corresponding innovation outcomes. Taking suppliers and non-OEM customers as knowledge sources

[46] It is worth noting that, as mentioned in Section 2.4.2.1, the positive relevance of markets as knowledge sources for patenting may be partially attributable to companies' preference for making use of formal institutions.

for developing innovative products as an example, with intensive sourcing activities, firms may not just focus on short-term revenue and source only non-technical skills from their suppliers or non-OEM customers to enhance their innovation sales. They also source technical skills as inputs to develop innovative products to sustain their long-term development.

In addition, results show that the usage intensity of ‘OEM customers’ and ‘companies from the same enterprise group’, which were found to be significantly but negatively relevant for realising above-average innovation sales, also matters. This suggests that using these knowledge sources turns to be less restrictive against realising high innovation sales when they are used more intensively. However, such results may be, to some extent, externally determined through the positive effects of using such knowledge sources intensively on implementing innovative processes and on developing innovative products, respectively.

The third way to test the robustness of the estimation results of the baseline models is also an attempt to generalise the results shown above. As mentioned in Section 2.4.1, estimation results till now may only be valid for clarifying the knowledge production processes among firms which indeed successfully carry out innovative outcomes. In order to take firms which made efforts to innovate but do not yet carry out innovation outcomes into account, a probit selection model is estimated simultaneously in addition to the baseline KPF model and it regresses companies’ success of carrying out innovation outcomes to some innovation determinants suggested by the literature. Table 2.4 presents the estimation results of the corresponding extended models.

	product	process	innosales	patent
	(1)	(2)	(3)	(4)
lnexprdtr	0.762*	-0.040	1.889***	0.193
	(0.395)	(0.091)	(0.416)	(0.130)
oem_dm	-1.185**	0.465*	-0.977**	-0.137
	(0.505)	(0.270)	(0.394)	(0.350)
supnoem_dm	0.598	0.029	0.865**	-0.813**
	(0.378)	(0.262)	(0.436)	(0.361)
compet_dm	-0.359	-0.303	0.872*	-0.280
	(0.317)	(0.207)	(0.448)	(0.308)
uni_dm	0.509	-0.025	0.849**	0.489
	(0.375)	(0.161)	(0.335)	(0.395)
mkt_dm	0.822**	0.236	-0.527	0.765**
	(0.327)	(0.204)	(0.417)	(0.385)
group_dm	0.541*	0.193	-1.073***	0.420
	(0.322)	(0.153)	(0.360)	(0.276)
pers_dm	-0.635	-0.142	-0.620	0.134
	(0.399)	(0.270)	(0.413)	(0.278)
lnsize	-0.059	0.195**	0.062	0.027
	(0.217)	(0.093)	(0.174)	(0.162)
age	0.021	0.025	0.034	0.027
	(0.030)	(0.023)	(0.040)	(0.027)
exporter	-0.405	-0.049	0.756*	-0.118
	(0.507)	(0.202)	(0.418)	(0.305)
foreignown~o	0.354	0.374	-0.305	0.039
	(0.466)	(0.279)	(0.409)	(0.308)
foreignown~i	-0.786	0.074	0.172	-1.370***
	(0.713)	(0.269)	(0.513)	(0.500)
_cons	1.023	-1.047**	-4.371***	-0.295
	(1.220)	(0.454)	(0.955)	(0.683)
inno				
lnsize	0.186***	0.179***	0.186***	0.182***
	(0.032)	(0.000)	(0.032)	(0.033)
mktcompet_md	0.566*	0.102	0.409	0.607*
	(0.303)	(0.219)	(0.299)	(0.318)
mktcompet_st	0.429	-0.241	0.244	0.422
	(0.301)	(0.202)	(0.292)	(0.314)
manuf	0.056	0.100***	0.051	0.056
	(0.166)	(0.000)	(0.162)	(0.151)
_cons	-0.861**	-0.325	-0.688**	-0.847***
	(0.341)	(0.202)	(0.338)	(0.326)
/atanhrho_12	-2.839**	15.229	0.375	0.788
	(1.233)	(14.402)	(0.427)	(0.816)
rho_12	-0.993	1.000	0.358	0.657
	(0.017)	(0.000)	(0.373)	(0.464)
Obs.	197	198	197	199
Wald Chi2	29.16***	9.595e+5***	50.15***	25.02**

Notes: ***/**/* refer to 1%/5%/10% significance level. Robust standard errors are presented in parentheses.

Table 2.4 – Estimation Results of the Extended Firm-level Knowledge Production Function Considering Selection Bias Problem by Innovation Outcome (Estimated Coefficients of the Extended Models)

Table 2.4 shows that the correlation between the error term in the baseline KPF model and the error term in the probit selection model are not significantly different from zero in cases of having innovative processes, innovation sales and patenting as innovation outcomes.[47] This finding suggests that the potential problem that firms made innovation efforts but do not yet come out with innovation outcomes is not significant at least for the cases with these three innovation outcomes. Firms which made innovation efforts for carrying out these three types of innovation outcomes seem to be able to accomplish their innovation activities and come out with some results. In other words, the findings of the baseline models with these three innovation outcomes are robust and can be used to describe the corresponding knowledge production processes in general.

In contrast, the correlation between the error term in the baseline KPF model with innovative products as innovation outcome and the error term in the probit selection model is found to be significantly different from zero. The negative sign of the correlation suggests that the findings of the baseline KPF model may be overestimated, if the findings are to be used to interpret all firms' product innovation activities in general. Although results suggest that innovative firms seem to more productively use innovation inputs to come out with innovative products, innovation inputs which are found to be significant in the extended model are the same as the innovation inputs which were found to be significant in the corresponding baseline KPF model above.

2.5 Conclusion

This chapter analysed an original firm-level dataset collected in the PRD in China. It estimated firm-level KPF models, based on the KPF concept proposed by Criscuolo et al. (2005) and Wagner (2006) to investigate knowledge production processes of the electronics firms in the PRD in China. It aimed to clarify whether firms in China as the second-tier follower in the FG model may innovate in a similar way as companies in the Asian NIEs did in the past and whether they use various knowledge sources to support them to carry out different innovation outcomes. In particular, it attempted to gain more insights into the role of universities for firms' various innovation activities in China against the background of a traditional division of labour between universities and firms for many years.

[47] The parameter 'rho' is bounded in value. Thus, it is not suitable for being used as a base for testing the null hypothesis that correlation between error terms is equal to zero. Instead, the parameter 'rho' is transformed into an unbounded scale for test by using its arc-hyperbolic tangents 'atanhrho' (Roodman, 2009).

Descriptive analysis in this paper showed that firms in the PRD in China do not seem to innovate completely in the same way as their counterparts in the Asian NIEs did decades ago. We found that, on the one hand, innovative companies in the PRD rely on the same sources such as parent company, joint ventures and OEM customers as their counterparts in the Asian NIEs to extend their innovation capabilities. And they also carry out innovative processes over time. On the other hand, locally well-educated workers in addition to workers trained abroad are highly appreciated as knowledge sources for innovative firms in the PRD. This may be attributable to the higher education reform in China since the late 1990s which has substantially increased the local supply of highly qualified workers. Moreover, we found that some of the innovative firms in the PRD already started to invest a lot in their own R&D activities and more firms perform product innovation activities successfully than process innovation activities. The last two points seemed to suggest that firms in the PRD in 2007 may be better equipped with human capital, technological capabilities and resources than their counterparts in the Asian NIEs when they started to innovate.

In order to clarify the role of different innovation inputs for various innovation outcomes in more detail, we estimated firm-level KPF models, considering four different innovation outcomes to proxy new knowledge created: innovative products, innovative processes, innovation sales and patenting. Estimation results of the baseline models, which considered firms' R&D expenditure and their usage of different knowledge sources to obtain innovation-related technologies and knowledge as innovation inputs and controlled for some firm-specific characteristics, are robust. Our estimation results are consistent with the findings of Criscuolo et al. (2005) for UK to great extent but less with Wagner (2006) for Germany. We found that firms in the PRD utilise different kinds of innovation inputs to carry out various innovation outcomes.

More concretely, we found firstly that innovative firms in the PRD rely strongly on their OEM customers as their knowledge sources to carry out innovative processes to increase their production efficiency. In contrast, they rely more on own R&D activities to develop innovative products, to realise higher innovation sales or to create new knowledge qualified enough for patenting, for which they hardly obtain technological support from their OEM customers. These findings are consistent with the findings in the case study literature in the Asian NIEs. Moreover, we found that innovative firms in the PRD rely on sourcing innovation-related information such as up-to-date information on customer needs and on technologies currently supplied from fairs and technical markets to carry out innovative products and to create new knowledge for patenting. Firms in the Asian NIEs seemed to hardly apply such sources decades ago, when the telecommunication techniques and transportation technologies were still quite underdeveloped. Underdeveloped technologies of these sorts may act as impediments against efficient information exchanges and against frequent visits of economic agents to technical markets worldwide.

Finally, we found that innovative firms in the PRD rely on utilising expertise of universities and research institutes to realise higher innovation sales or to create new knowledge qualified for patenting. Taking into account the descriptive results above that firms in the PRD tend to hire qualified workers to gain access to academic knowledge instead of sourcing knowledge directly from the universities as well, our findings suggest that, though university research may indeed matter, firms in China are not yet aware of the strength and relevance of academic research or there are some barriers hindering firms from sourcing directly knowledge and technologies from universities. To gain access to academic knowledge, firms in the PRD are restricted to using highly qualified workers as knowledge transmitters. Moving the analysis of this chapter to a broader research covering the mainland China and differentiating universities by their proximity to firms and their research quality is expected to help us better identify the significant barriers – geography- or quality-determined – hindering firms from engaging in active academia-industry linkages for innovation.

2.A Appendix

Five additional tables are presented here to provide further information related to Chapter 2.

Q1[a] ***(inno)***
a) Does your company carries out any innovation activities?
☐ yes➔*continue* ☐ no➔ *go to Q46/47/48/53/54& Fact sheet*[#]
b) How important are they? (1 – very important; 5- not important) *Leave blank, if not applied.*
1 2 3 4 5 Product innovation
1 2 3 4 5 Process innovation
1 2 3 4 5 Organisational innovation
1 2 3 4 5 Marketing innovation

Q2[b] **(ln*exprdtr*)**
Please, roughly estimate the overall innovation expenditure-to-sales ratio and the R&D-to-sales ratio in 2006, respectively. Overall: ___%; R&D:___%

Q3[b] **(*oem, supnoem, compet, uni, mkt, group, pers*)**
Please assess the importance of the following sources for innovation-related technology and knowledge. (1 – very important; 5 – not important) *Please leave blank, if not relevant.*
1 2 3 4 5 Parent, affiliated or Joint Venture companies
1 2 3 4 5 Hiring qualified workers
1 2 3 4 5 OEM customers
1 2 3 4 5 Suppliers or non-OEM customers
1 2 3 4 5 Companies in the same sector
1 2 3 4 5 Universities or research institutes
1 2 3 4 5 Fairs/technical markets
1 2 3 4 5 Others:___________________________

Q4[b] **(*product, process*)**
Please indicate your company's innovation outputs in the last 3 years? Which of the following points have been newly introduced or improved? *Multiple answers possible. Leave blank, if not applied.*

	new	improved	
Product functions	☐	☐	→ *used for 'product'*
Product quality	☐	☐	
Product designs	☐	☐	
Production methods	☐	☐	→ *used for 'process'*
Organisation of work	☐	☐	
Organisation of the relations to suppliers	☐	☐	
Organisation of the relations to customers	☐	☐	

Q5[b] **(*innosales*)**
What share of total sales is realised with these new and improved products (see Q49[#] [here Q4]**) in 2006?**
☐=0% 0<☐≤10% 10<☐≤25% 25<☐≤50% 50<☐≤75% 75<☐≤100%

Notes: [#]original question reference in the questionnaire; [a]addressed to all firms; [b]only addressed to innovative firms. The full questionnaire can be obtained from the author upon request. Source: Own PRD Company Survey 2007.

Table 2.A.1 – PRD Company Survey Questionnaire (Relevant Part)

Q6[a] **(*patent*)**
How does your company react to the risk of product piracy/imitation? <u>*Multiple answers possible; if no actions, please leave blank.*</u>
☐Apply for intellectual property rights → *used for patent*
☐Prefer locations with better IPR enforcement
☐Prefer members of personal networks as partners
☐More comprehensive contracts with partners
☐Prefer cheaper innovations to more expensive ones
☐Prefer own R&D to R&D cooperation projects
☐Prefer buying innovations developed by others
☐Less innovation investment in general
☐Others: ___________________________________

Q7[a] ***(sales)***
How many sales in RMB has your company realised in 2006?
❑<1 Mio 1≤❑<5 Mio 5≤❑<10 Mio 10≤❑<50 Mio 50≤❑<100 Mio ❑≥100 Mio

Q8[a] ***(lnsize)***
How many persons on average have been employed in your company during the last twelve months for the following functions.
In total: _____ → *used for 'lnsize'*
In production: normal ____ highest ____ lowest ____
In innovation overall: _____; thereof for R&D: _______

Q9[a] ***(age)***
In what year did your company start its operations in the PRD?
____

Q10[a] ***(exporter)***
What share of sales did your company generate with customers in the following regions in 2006? <u>*Sum of shares =100%*</u>
___% Chinese mainland ___% HK ___%TW
___% Japan ___% Other Asian countries
___% North America + Western Europe + Australasia ___% Rest of the world

Notes: [#]original question reference in the questionnaire; [a]addressed to all firms; [b]only addressed to innovative firms. The full questionnaire can be obtained from the author upon request. Source: Own PRD Company Survey 2007.

Table 2.A.1 (continued) – PRD Company Survey Questionnaire (Relevant Part)

Q11[a] ***(foreignown_to, foreignown_mi)***
How is your company registered in the PRD?
☐ Chinese-owned enterprise
☐ State-owned ☐ Collectively-owned ☐ Private
☐ Wholly foreign-owned enterprise (incl. HK, MA, TW)
☐ Chinese-foreign equity joint venture (incl. HK, MA, TW)
☐ Chinese-foreign cooperative joint venture (incl. HK, MA, TW)

Q12[a] ***(mktcompet_md, mktcompet_st)***
How has the intensity of competition changed for your company during the last 5 years?
☐ strongly increased ☐ moderately increased
☐ unchanged
☐ moderately decreased ☐ strongly decreased

Q13[a] ***(manuf)***
Where does your company perform the following activities? *<u>Leave blank if unit does not exist.</u>*

PRD	HK	Other	
☐	☐	☐	Management
☐	☐	☐	Finance
☐	☐	☐	Procurement
☐	☐	☐	Production
☐	☐	☐	Sales/Marketing
☐	☐	☐	Logistics/Distribution
☐	☐	☐	Innovation activities

Q14[a] ***(predict)***
Please, assess how predictable the following industry conditions have been for your company during the last 5 years. (1 – very predictable, 5 – not predictable)

1 2 3 4 5	Price of products
1 2 3 4 5	Volume of demand
1 2 3 4 5	Product sophistication
1 2 3 4 5	Delivery time
1 2 3 4 5	Availability of resources and suppliers
1 2 3 4 5	Availability of labour
1 2 3 4 5	Governmental regulations and policies

Q15[a] ***(careerceo)***
Where has the CEO/Managing Director of your company worked <u>directly</u> before taking this job?
☐ already in this company
☐ in a state-owned company
☐ in a private-owned company
☐ others ____________________________

Notes: [#]original question reference in the questionnaire; [a]addressed to all firms; [b]only addressed to innovative firms. The full questionnaire can be obtained from the author upon request. Source: Own PRD Company Survey 2007.

Table 2.A.1 (continued) – PRD Company Survey Questionnaire (Relevant Part)

	oem	supnoem	compet	uni	mkt	group	pers
N	152	152	153	152	153	153	152
n_use	77	75	76	62	81	85	102
of							
1	18 (23%)	15 (20%)	16 (21%)	16 (26%)	23 (28%)	37 (44%)	52 (50%)
2	32 (42%)	21 (28%)	19 (25%)	11 (18%)	24 (30%)	19 (22%)	30 (29%)
3	14 (18%)	27 (36%)	20 (26%)	10 (16%)	18 (22%)	14 (16%)	15 (14%)
4	6 (8%)	4 (5%)	10 (13%)	10 (16%)	8 (10%)	4 (5%)	6 (6%)
5	7 (9%)	8 (11%)	11 (15%)	15 (24%)	8 (10%)	11 (13%)	2 (2%)

Notes: N refers to the number of innovative firms with valid responses to the survey question regarding knowledge sources. n_use refers to the number of innovative firms using knowledge sources considered. A 5-level Likert scale was used for assessing the importance of knowledge sources considered, when firms use them: 1 – very important; 2 – important; 3 – of normal importance; 4 – a little important; 5 – not important. Source: Own PRD Company Survey 2007.

Table 2.A.2 – Company Distribution by Importance of Different Knowledge Sources

	Variable description	Mean	Std. Dev.	Min	Max	Obs
Innovation outcomes (Y)						
product	Introducing products with new or improved functions into markets (1) or not (0)	0.918	0.276	0	1	134
process	Carrying out new or improved production methods (1) or not (0)	0.813	0.391	0	1	139
innosales	Realising above-average innovation sales (1) or not (0)	0.450	0.499	0	1	129
lninnosalescal	Innovation sales (calculated value) in log	2.048	2.412	-2.436	7.265	129
patent	Applying for patents to react to risks of product piracy (1) or not (0)	0.766	0.425	0	1	145
Innovation inputs (X^{rd} & X^{tt})						
lnexprdtr	R&D expenditure in log	2.270	1.449	1.000	6.687	141
oem_dm	Souring innovation-related knowledge from OEM customers (1) or not (0)	0.507	0.502	0	1	152
oem_md	Assessing OEM customers as a little or normally important knowledge source (1) or not (0)	0.132	0.339	0	1	152
oem_st	Assessing OEM customers as important or very important knowledge source (1) or not (0)	0.329	0.471	0	1	152
supnoem_dm	Souring innovation-related knowledge from suppliers or non-OEM customers (1) or not (0)	0.493	0.502	0	1	152
supnoem_md	Assessing suppliers or non-OEM customers as a little or normally important knowledge source (1) or not (0)	0.204	0.404	0	1	152
supnoem_st	Assessing suppliers or non-OEM customers as important or very important knowledge source (1) or not (0)	0.237	0.427	0	1	152

Source: Own PRD Company Survey 2007.

Table 2.A.3 – Variable Description and Basic Descriptive Statistics of Variables Considered in the Estimated Regression Models

	Variable description	Mean	Std. Dev.	Min	Max	Obs
Innovation inputs (X^{it})						
compet_dm	Souring innovation-related knowledge from companies from the same industry (1) or not (0)	0.497	0.502	0	1	153
compet_md	Assessing companies from the same industry as a little or normally important knowledge source (1) or not (0)	0.196	0.398	0	1	153
compet_st	Assessing companies from the same industry as important or very important knowledge source (1) or not (0)	0.229	0.421	0	1	153
uni_dm	Souring innovation-related knowledge from universities or research institutes (1) or not (0)	0.408	0.493	0	1	152
uni_md	Assessing universities or research institutes as a little or normally important knowledge source (1) or not (0)	0.132	0.339	0	1	152
uni_st	Assessing universities or research institutes as important or very important knowledge source (1) or not (0)	0.178	0.383	0	1	152
mkt_dm	Souring innovation-related knowledge from fairs or technical markets (1) or not (0)	0.529	0.501	0	1	153
mkt_md	Assessing fairs or technical markets as a little or normally important knowledge source (1) or not (0)	0.170	0.377	0	1	153
mkt_st	Assessing fairs or technical markets as important or very important knowledge source (1) or not (0)	0.307	0.463	0	1	153
group_dm	Souring innovation-related knowledge from parent company, affiliated companies or joint ventures (1) or not (0)	0.556	0.499	0	1	153
group_md	Assessing parent company, affiliated companies or joint ventures as a little or normally important knowledge source (1) or not (0)	0.118	0.323	0	1	153
group_st	Assessing parent company, affiliated companies or joint ventures as important or very important knowledge source (1) or not (0)	0.366	0.483	0	1	153
pers_dm	Souring innovation-related knowledge by hiring highly qualified workers (1) or not (0)	0.691	0.464	0	1	152
pers_md	Assessing recruitment of highly qualified workers as a little or normally important knowledge source (1) or not (0)	0.138	0.346	0	1	152
pers_st	Assessing recruitment of highly qualified workers customers as important or very important knowledge source (1) or not (0)	0.539	0.500	0	1	152

Source: Own PRD Company Survey 2007.

Table 2.A.3 (continued) – Variable Description and Basic Descriptive Statistics of Variables Considered in the Estimated Regression Models

	Variable description	Mean	Std. Dev.	Min	Max	Ob
Control variables and others						
lnsize	Number of employees in log	5.117	1.542	0.693	10.309	213
age	Company age	8.685	6.297	0	1	219
exporter	Engaging in export business (1) or not (0)	0.743	0.438	0	1	214
foreignown_to	Totally foreign-owned companies (1) or not (0)	0.341	0.475	0	1	217
foreignown_mi	Owned by Chinese and foreign investors (1) or not (0)	0.088	0.283	0	1	217
inno	Carrying out innovation activities (1) or not (0)	0.715	0.452	0	1	221
mktcompet_md	Facing moderately increasing competition pressure (1) or not (0)	0.356	0.480	0	1	222
mktcompet_st	Facing strongly increasing competition pressure (1) or not (0)	0.590	0.493	0	1	222
manuf	Having production operations (1) or not (0)	0.913	0.283	0	1	195
predict	Being able to at least a little bit predict policy changes (1) or not (0)	0.778	0.417	0	1	216
careerceo	CEO worked in a state-owned enterprise of other private company before working as CEO in the current company (1) or not (0)	0.306	0.462	0	1	219

Source: Own PRD Company Survey 2007.

Table 2.A.3 (continued) – Variable Description and Basic Descriptive Statistics of Variables Considered in the Estimated Regression Models

	product	process	innosales	patent
	(1)	(2)	(3)	(4)
lnexprdtr	1.533*	-0.276*	2.389***	0.294*
	(0.831)	(0.166)	(0.539)	(0.161)
oem_md	-2.559***	1.106*	-2.086**	-0.228
	(0.976)	(0.609)	(0.806)	(0.606)
oem_st	-2.897***	1.458***	-1.032**	-0.515
	(1.091)	(0.472)	(0.450)	(0.402)
supnoem_md	0.387	0.978	2.410***	-0.412
	(0.664)	(0.728)	(0.804)	(0.632)
supnoem_st	2.212***	0.720	0.724	-0.901**
	(0.801)	(0.535)	(0.496)	(0.438)
compet_md	0.855	-1.751***	0.842	0.389
	(0.637)	(0.612)	(0.651)	(0.491)
compet_st	-0.237	0.010	0.533	0.030
	(0.566)	(0.466)	(0.432)	(0.465)
uni_md	-2.587***	-0.448	1.014*	1.749***
	(0.674)	(0.553)	(0.537)	(0.633)
uni_st	-[a]	0.199	1.126***	1.178**
	-[a]	(0.510)	(0.424)	(0.525)
mkt_md	1.142	0.894	-1.737**	0.074
	(0.755)	(0.711)	(0.679)	(0.658)
mkt_st	2.310***	0.497	-0.658	1.469***
	(0.569)	(0.532)	(0.520)	(0.466)
group_md	-[b]	1.322**	-2.299***	-[c]
	-[b]	(0.641)	(0.807)	-[c]
group_st	2.481***	0.187	-0.828*	0.684*
	(0.643)	(0.429)	(0.457)	(0.372)
pers_md	-0.936	-1.214**	-0.434	0.861
	(0.702)	(0.592)	(0.530)	(0.533)
pers_st	-0.328	-0.211	-0.532	-0.212
	(0.715)	(0.373)	(0.425)	(0.364)
Obs.	83	120	116	109
Wald Chi2	40.44***	43.03***	40.35***	53.70***
Pseudo R2	0.460	0.280	0.604	0.339

Notes: [a]Uni_st is dropped due to perfect success prediction; thus 21 observations are not used. [b]Group_md is dropped due to its perfect success prediction; thus 13 observations are not used. [c]Group_md is dropped due to its perfect success prediction; thus 13 observations are not used. To save space, estimation results of control variables and constants are not shown here. ***/**/* refer to 1%/5%/10% significance level. Robust standard errors are presented in parentheses.

Table 2.A.4 – Estimation Results of Extended Firm-level Knowledge Production Function with Importance Measures of Knowledge Sources by Innovation Outcome (Estimated Coefficients of the Extended Models)

	product Baseline (1)	product Extended (2)	process Baseline (3)	process Extended (4)	innosales Baseline (5)	innosales Extended (5)	patent Baseline (7)	patent Extended (8)
Pr(Y=1)	0.996	0.999	0.727	0.732	0.797	0.819	0.800	0.728
lnexprdtr	0.010	0.003	-0.025	-0.091	0.551**	0.630*	0.065	0.098
	(0.017)	(0.008)	(0.050)	(0.059)	(0.245)	(0.354)	(0.044)	(0.060)
oem_dm	-0.091		0.199**		-0.363**		-0.046	
	(0.098)		(0.094)		(0.152)		(0.119)	
oem_md		-0.243		0.226**		-0.699***		-0.080
		(0.272)		(0.105)		(0.191)		(0.226)
oem_st		-0.359		0.249**		-0.367**		-0.191
		(0.307)		(0.116)		(0.158)		(0.162)
supnoem_dm	0.004		0.086		0.161		-0.308*	
	(0.007)		(0.113)		(0.117)		(0.161)	
supnoem_md		0.000		0.213*		0.181		-0.151
		(0.001)		(0.124)		(0.197)		(0.241)
supnoem_st		0.001		0.178		0.130		-0.344**
		(0.002)		(0.111)		(0.123)		(0.163)
compet_dm	-0.007		-0.221		0.160		-0.085	
	(0.014)		(0.154)		(0.129)		(0.121)	
compet_md		0.001		-0.603***		0.142		0.112
		(0.002)		(0.144)		(0.142)		(0.127)
compet_st		-0.001		0.003		0.107		0.010
		(0.003)		(0.153)		(0.115)		(0.151)
uni_dm	0.003		-0.001		0.159		0.127	
	(0.007)		(0.124)		(0.126)		(0.078)	
uni_md		-0.251		-0.164		0.154		0.263**
		(0.297)		(0.216)		(0.157)		(0.133)
uni_st		-[a]		0.061		0.161		0.235*
		-[a]		(0.150)		(0.162)		(0.124)
mkt_dm	0.004		0.148*		-0.183		0.156**	
	(0.008)		(0.087)		(0.184)		(0.079)	
mkt_md		0.001		0.203*		-0.614***		0.024
		(0.002)		(0.111)		(0.195)		(0.206)
mkt_st		0.001		0.136		-0.219		0.253**
		(0.002)		(0.114)		(0.233)		(0.123)
group_dm	0.004		0.071		-0.402**		0.105	
	(0.007)		(0.101)		(0.163)		(0.072)	
group_md		-[b]		0.242**		-0.736***		-[c]
		-[b]		(0.121)		(0.177)		-[c]
group_st		0.001		0.058		-0.286		0.173*
		-		(0.129)		(0.188)		(0.100)

Notes: Reference point for measuring the marginal effects: dependent variable is set equal to one, respectively. All metric independent variables are set at their mean levels, and all binary independent variables are set equal to 0 due to the existing exclusiveness between complementary dummy variables. [a]Uni_st is dropped due to perfect success prediction; thus 21 observations are not used. [b]Group_md is dropped due to its perfect success prediction; thus 13 observations are not used. [c]Group_md is dropped due to its perfect success prediction; thus 13 observations are not used. ***/**/* refer to 1%/5%/10% significance level. Standard errors are presented in parentheses.

Table 2.A.5 – Estimation Results of the Baseline Models and the Extended Models with Importance Measures by Innovation Outcome (Estimated Marginal Effects)

	product Baseline (1)	product Extended (2)	process Baseline (3)	process Extended (4)	innosales Baseline (5)	innosales Extended (5)	patent Baseline (7)	patent Extended (8)
pers_dm	-0.020		-0.124		-0.227		0.022	
	(0.039)		(0.129)		(0.140)		(0.088)	
pers_md		-0.010		-0.456**		-0.136		0.201
		(0.022)		(0.197)		(0.177)		(0.127)
pers_st		-0.001		-0.074		-0.171		-0.074
		(0.004)		(0.132)		(0.142)		(0.128)
lnsize	-0.000	-0.000	0.050	0.085	0.010	0.067	-0.013	-0.002
	(0.003)	(0.001)	(0.055)	(0.053)	(0.048)	(0.062)	(0.047)	(0.056)
age	0.000	-0.000	0.011	0.021	0.009	0.007	0.007	0.015
	(0.001)	(0.000)	(0.008)	(0.013)	(0.011)	(0.011)	(0.009)	(0.013)
exporter	-0.012	-0.051	-0.079	-0.182	0.148	0.162	-0.033	-0.024
	(0.021)	(0.102)	(0.144)	(0.184)	(0.133)	(0.172)	(0.106)	(0.142)
foreignown_to	0.003	0.001	0.208**	0.216**	-0.098	-0.124	0.023	0.010
	(0.006)	(0.002)	(0.099)	(0.107)	(0.140)	(0.157)	(0.091)	(0.122)
foreignown_mi	-0.036	-0.006	0.108	0.189	0.049	0.076	-0.553***	-0.634***
	(0.078)	(0.016)	(0.153)	(0.120)	(0.136)	(0.134)	(0.130)	(0.115)

Notes: Reference point for measuring the marginal effects: dependent variable is set equal to one, respectively. All metric independent variables are set at their mean levels, and all binary independent variables are set equal to 0 due to the existing exclusiveness between complementary dummy variables. [a]Uni_st is dropped due to perfect success prediction; thus 21 observations are not used. [b]Group_md is dropped due to its perfect success prediction; thus 13 observations are not used. [c]Group_md is dropped due to its perfect success prediction; thus 13 observations are not used. ***/**/* refer to 1%/5%/10% significance level. Standard errors are presented in parentheses.

Table 2.A.5 (continued) – Estimation Results of the Baseline Models and the Extended Models with Importance Measures by Innovation Outcome (Estimated Marginal Effects)

3 The Role of Proximity to University Research for Industrial Patenting

A revised and short version of this chapter is accepted by the Annals of Regional Science (©Springer-Verlag Berlin Heidelberg 2012) and is available online (Liu, W.-H. (forthcoming), The Role of Proximity to Universities for Corporate Patenting - Provincial Evidence from China, DOI: 10.1007/s00168-012-0540-2)

For the working paper version of this chapter see Liu, W.-H. (2012), The Role of Proximity to Universities for Corporate Patenting - Provincial Evidence from China, Kiel Working Paper 1796, Kiel Institute for the World Economy (http://www.ifw-members.ifw-kiel.de/publications/the-role-of-proximity-to-universities-for-corporate-patenting-provincial-evidence-from-china).

3.1 Introduction

The analysis in Chapter 3 focuses exclusively on the role of university research for industrial patenting but it generalises the corresponding analysis in Chapter 2 in three aspects: regional and geographic aspect, sectoral aspect and the university quality aspect. The more generalised analysis enables a better comparison with related literature emerged since the late 1980s for Western economies.

Companies with long-term profit maximisation as their goal undertake innovation activities to introduce new products and to develop new technologies to enhance their market competitiveness. In terms of input, they invest considerable amounts of financial resources and human capital in their own research and development (R&D) activities to explore new knowledge as a base for novel products. In addition, they may acquire externally available new knowledge and build their R&D activities on existing knowledge to develop their products. In the latter case learning from others enables them to focus limited resources on key innovation activities, thereby increasing their efficiency in producing innovation outcomes given the same amount of innovation inputs invested (e.g. Mansfield, 1991).

Academic institutions like universities are considered to be one of the major knowledge sources to spur companies' patenting activities (see Chapter 2 and e.g. Criscuolo et al., 2005; Wagner, 2006; Liu, 2009). Traditionally, publically funded universities focus on basic research to explore new knowledge in order to expand the public knowledge stock to the benefit of society as a whole. In basic research, research outcomes and related pay-offs are often difficult to be adequately appropriated by innovators. In line with their objective to expand the public knowledge stock, universities are expected to share their research findings with others through publications, presentations, conferences and workshops to which external innovators may have easier access at relatively low cost. The latitude of universities to share their knowledge with external innovators has been further expanded by the Bayh-Dole Act of 1980 in the US and by similar policies in the other industrialised countries (Mowery et al., 2004). Universities have been then given the right to file patents for their publicly financed inventions. This is expected to encourage universities to make their research findings more concrete in order to be more easily applied by industries (Cohen et al., 2002). Nevertheless, despite some convergence in the wake of these policy changes, there remains a gap between universities and companies in research focus, commercial will and the modus operandi. Therefore, companies which are in need of academic knowledge for new projects and/or for solving problems confronted with during their innovation processes have to communicate and interact with academic researchers to ensure a more efficient use and transformation of academic knowledge.

The efficiency of these knowledge transfer and/or knowledge spillover processes may thus have an essential spatial element: it is more advantageous for developing corporate innovation outcomes if companies are located closer to their (potential) academic knowledge sources. The clustering of industrial innovators close to University of California, Berkeley and Stanford University (Silicon Valley) and to Massachusetts Institute of Technology and Harvard University (Route 128) in the United States (US) was often alluded to as support for this hypothesis (Dorfman, 1983). The seminal work of Jaffe (1989) on estimating regional knowledge production functions led to a series of studies focusing on this topic. Most of them found evidence supporting the hypothesis that academic research has a positive impact on corporate innovation outcomes and that such positive effects decrease over distance.

However, most of the studies until now strongly focused on industrialised countries such as the US but not on emerging economies like China, though China has played an increasingly important role in global knowledge production processes (WIPO, 2010). This is especially true since the turn of the century. In the case of China, such spatial spillover effects of academic research on corporate innovation outcomes can be even more strongly expected. The traditional division of labour in China which required companies to focus on production activities and universities on research makes it more crucial for companies which lack innovation experience but are now encouraged and/or forced to engage in innovation activities to interact with universities and to make use of academic research results more efficiently to develop new products and/or technologies.

Focusing on the case of China, this chapter analyses the spatial effects of academic research on corporate innovation performance based on a Chinese provincial panel dataset from 2000 to 2008. To measure the potential accessibility of companies to academic knowledge, taking distance between companies and universities into account, the logsum accessibility indicator is calculated. The logsum accessibility indicator, different from the indicators considered in Jaffe (1989) and Anselin et al. (1997), captures the individuals' utility maximising goal which implies that the individuals/companies will seek to access a maximal relevant amount of appropriable academic knowledge available to them.[48] Applying the knowledge production framework, this chapter regresses corporate innovation outcomes on companies' own R&D efforts and their accessibility to academic knowledge, controlling for other firm- and industry-related as well as region-specific influential factors based on the literature. It investigates whether spatial spillover effects of academic knowledge on corporate innovation outcomes differ across academic knowledge embodied in different forms and across different corporate innovation outcomes considered.

The structure of this chapter is organised as follows. Section 3.2 briefly summarises the literature on spatial spillover effects of academic research on corporate innovation outcomes. Section 3.3 introduces the dataset for our analysis and some key statistics to provide a broad picture about the development in corporate innovation activities and in academic knowledge production processes over the past decade in China. After that the logsum accessibility indicator and the estimation models for further analysis are described in some detail. Section 3.4 presents the estimation results of both baseline models and extended models for robustness checks, dealing with issues such as endogeneity problem and serial and spatial autocorrelations. Section 3.5 concludes.

3.2 Related Literature

Academic research carried out by universities is to great extent financed by governments. Depending on governments' policy focus, universities may restrict their research on research areas where market failure exists and companies lack R&D

[48] See Section 3.3.2 and Ben-Akiva and Lerman (1985) for more information.

interests or they may extend their research to more applied research areas in order to explore and develop new knowledge for industrial usage (Bozeman, 2000). The amount of financial resources and human capital invested in the academic research processes does not guarantee per se that the academic findings can be fully realised. University researchers may well present key academic findings in publications such as books and journal articles, and/ or in patent-related documents. They may not document as comprehensively the less crucial part of academic findings; but this part of their knowledge may still be relevant as context information advantageous for understanding the documented/codified key academic findings. The non-codified findings remains as tacit information which represents another component of academic knowledge accumulated over time and which can only be transmitted to others via direct communications and interactions. Tacit information may also include knowledge and the experience about dead-end research.

The borderline and the relationship between codified knowledge and tacit information are not without controversy. While Dasgupta and David argued that codified knowledge and tacit information can be “two substitutable inputs (at the margin) in production of further knowledge” (Dasgupta and David, 1994: 494), factor analyses of Cohen et al. (2002) suggested that personal interactions, which are the major ways to transmit tacit information, tend to complement, in particular, publically available codified knowledge such as publications. In the latter case, in which (at least a great part of) codified academic knowledge can be understood better by companies via personal interactions and communications with university researchers, distance between companies and universities may affect how efficiently the ‘theoretically boundary-unrestricted’ codified academic knowledge can be used as additional inputs to improve companies’ innovation productivity. Distance, as such, even plays a more important role in the event that companies are only keen on obtaining academic researchers’ tacit information but not their documented knowledge for innovation support. Indeed Storper and Venables (2004) argued, although they do not focus solely on interactions between companies and universities, that proximity may promote knowledge transfers and spillovers because it eases face to face contact. They argued, based on self-developed theoretical models, that “face to face contact is particularly important in environments where information is imperfect, rapidly changing, and not easily codified” (Storper and Venables, 2004: 351).

That proximity between companies and universities may be advantageous for spurring industrial innovations, is illustrated by conspicuous cases in point in both industrialised countries as well as in emerging economies. The most well known and well investigated cases are the clustering of technologically advanced companies in Silicon Valley in the US state of California and near Route 128 in the US state of Massachusetts. Despite their differences in their respective industrial trajectories and their major product specialities, there is a crucially important factor comparably important for determining both regions' high-tech development: the existence of first-class academic centres of knowledge and on-site excellence. For Silicon Valley the relevant academic centres are University of California, Berkeley and Stanford University and for Route 128 they are Harvard University and Massachusetts Institute of Technology (Dorfman, 1983). Comparable examples can also be found in Asia such as Hsinchu Science Park in Taiwan (NCTU and NTHU[49]) (Chen and Choi, 2004) and Zhongguancun in Beijing in China (Peking University and Tsinghua University) (Zhou, 2005).

While case study literature provided more detailed context about the institutional framework, economic background and industrial trajectories of some selected real world examples of high-tech clusters with academic centres of excellence, the seminal work of Jaffe (1989) led to a series of econometric studies focusing on investigating the role of proximity to universities and university research for corporate innovation performance. Under a modified Griliches knowledge production function framework[50] Jaffe (1989) analysed US state-level data for various years[51] to examine the spatial spillover effect of university research on companies' knowledge production activity where companies' new knowledge was proxied by the number of corporate patents. He considered two proximity-related variables in his regression model. Firstly, he considered university R&D expenditure in the same state as the corporate patents filed, implying that university research carried out beyond the state boundary was assumed to be too far away for the potential industrial knowledge receivers to adequately profit from the

[49] NCTU and NTHU refer to National Chiao Tung University and National Tsing Hua University, respectively.
[50] See Griliches (1979) for more information about the idea and the construction of the knowledge production function framework.
[51] Limited by data availability he analysed data for 29 states only, for which data were complete for years 1972-1977, 1979 and 1981. See Jaffe (1989) for more information.

academic knowledge.[52] Secondly, to consider the proximity issue within states as well, he constructed a geographic coincidence index (GCI) which measured how concentrated university research and industrial labs were located across cities within states. Multiplying GCI by the variable of state-level university R&D, he built an interaction term for his regression model. Here the GCI was expected to reflect the role of university-industry concentration for intensifying the spillover effect of university research within states. His analysis found some support for the relevance of spatial spillover effects from university R&D for corporate patenting activity, but such effect was still much smaller than the contribution of industrial R&D to corporate patent outputs. Regarding the role of GCI as an intensifier of the spillover effect, Jaffe (1989) only found weak evidence.

Based on a slightly different cross-sectional dataset for 29 states, Acs et al. (1992) reestimated the regional knowledge function with the two proximity-related variables developed by Jaffe (1989). They used the number of innovations[53] instead of the number of corporate patents[54] to more directly proxy the industrial innovation performance. Their analysis basically strengthened the findings of Jaffe (1989). They found that, when considering a more direct measure of new industrial knowledge produced, the spillover effect of university research on corporate innovation performance was even more pronounced. Moreover, their analysis suggested that the GCI as a spillover-effect intensifier actually affected corporate innovation performance more strongly than had been suggested by Jaffe (1989).

Further improvements in the dataset and modelling procedure were made by Anselin et al. (1997 & 2000) when investigating the proximity issue. Anselin et al. (1997) extended the state-level dataset, which was also used by Acs et al. (1992), to 43 states and they formulated four alternatives for the original GCI (-based interaction term)

[52] Since Jaffe (1989) did not explicitly consider university R&D beyond the own state boundary, he emphasised that "(his) results do not relate directly to the question of the social rate of return to university research. They underestimate that return, to the extent that spillovers flow beyond state boundaries" (Jaffe, 1989: 968).

[53] "…the number of innovations (was) recorded in 1982 by the US Small Business Administration from the leading technology, engineering, and trade journals in each manufacturing industry" (Acs et al., 1992: 364). The record of innovation was made subsequently after the market introduction of the innovation considered.

[54] Knowledge per se is an intangible good which is difficult to be measured adequately. Using patent data to proxy knowledge produced is a convenient way but not without drawbacks. For example, not all innovations are patented and the 'value' of patented innovations can be significantly different across innovations. Some patented innovations are worth being further transformed into new products for markets but others may remain in shelves for many years. See Pakes and Griliches (1980a & 1980b) and Griliches (1990) for more information.

developed by Jaffe (1989) to proxy the within-state concentration between university and industrial research. Three of these four alternative indices were derived from the spatial interaction theory.[55] Parallel to the state-level analysis, they, for the first time for an analysis of this kind, examined the proximity issue at a more disaggregated level, i.e., at the level of metropolitan statistical areas (MSA). Here, they did not need to proxy the within-state industry-academy concentration by using the GCI measure from Jaffe (1989) or related alternatives. Instead, since the MSA level is a much more disaggregated spatial unit than the state level, they used spatial lag variables to measure the extent of university research in the MSA itself and in neighbouring counties with geographic centres not farther than 50 miles and 75 miles[56] away respectively from the geographic centre of the MSA considered. Anselin et al. (2000) further extended the MSA-level dataset analysed in Anselin et al. (1997) to a 'sectorally' disaggregated dataset. Moreover, when necessary, they applied spatial econometrics techniques to cope with potential spatial dependence problems of the cross-sectional dataset. All the improvements made by these two studies again provided support for the previous findings that university research exerted positive spillover effects on industrial innovation performance. Such spillover effects declined over distance but were not restricted to the boundaries of counties. However, Anselin et al. (2000) pointed to the existence of sectoral heterogeneity when deriving the magnitude of the academic spillover effect.

Research on the academic spillover effect on corporate innovative performance has also been carried out using data for some selected European industrialised countries. The regional knowledge production function of Jaffe (1989) was directly applied with slight revisions by Piergiovanni and Santarelli (2001) using French data at the NUTS-2[57] regional level. They proxied regional academic knowledge by using university R&D expenditure per R&D personnel and considered the GCI as an individual variable in the regression model. Their finding of a significantly positive coefficient with respect to academic research suggested that the existence of positive academic spillover on corporate performance did not seem to be a phenomenon only restricted to the US economy.

[55] The first indicator is a gravity measure (distance decay parameter equal to 2) and the other two indices are a kind of covering measures. See Anselin et al. (2000) for more information.
[56] '75-mile category' refers to counties with geographic centres located farther than 50 miles but not more than 75 miles away from the geographic centre of the MSA considered.
[57] The abbreviation 'NUTS' refers to 'Nomenclature of Units for Territorial Statistics'.

Barrio-Castro and Garcia-Quevedo (2005) focused on the case of Spain (NUTS-2 level). They did not consider GCI-related variables but directly considered academic research in both own region and in the neighbouring regions in the regression model. They found that regional academic research measured in university R&D expenditure exerted a significantly positive influence on corporate patenting performance in the Spanish case as well. Academic research carried out in neighbouring region seemed to lose its relevance in this regard, however. Similarly, Fischer and Varga (2003) considered the impact of non-local academic knowledge on regional corporate innovation performance. To consider the spatially discounted feature of the relevance of academic knowledge, the academic knowledge relevant for industrial innovation in the political district *i* in the regression model was measured as the sum of university research expenditure of the district and the distance-discounted non-local university research expenditure based on a positive distance decay parameter. Despite such measurement difference, Fischer and Varga (2003) found further evidence of spatial academic spillover effects as found in the previous literature.

Blind and Grupp (1999) extended related research to the German case and focused on two German NUTS-1 regions (Baden-Wuerttemberg and North Rhine-Westphalia). In contrast to most of the US studies, they proxied university research with patent applications of professors and they considered neither the within-region interaction between industry and academy (e.g. GCI) nor spatial lag variables. Still their findings that university research in both regions significantly positively affected the corporate patenting activities in the technological areas provided some support to the findings for US studies.

Last but not least, Piergiovanni et al. (1997) deepened the research topic by differentiating corporate innovation activities by firm size to investigate whether academic research may matter differently for firms of different sizes. Combining the approach used by Jaffe (1989) and Acs et al. (1992), Piergiovanni et al. (1997) proxied corporate innovation outcomes by two different variables: number of patents and number of innovations. Their analysis was based on Italian provincial or more aggregated regional data, depending on the innovation outputs under consideration. They measured academic knowledge based on university R&D expenditure in line with most of the abovementioned literature.[58] Their results did not just confirm the US

[58] Both innovation output variables and the university R&D expenditure were measured at the per capita base for regression analysis.

findings for a positive spillover effect of academic research on corporate innovation performance in Italy. Their results also suggested that such positive spillover effects were especially prominent for small firms than for larger firms.

That companies' own R&D efforts strongly matter for their innovation outcomes was also confirmed by the abovementioned regional studies for the US and Europe and in Feldman and Florida (1994). The latter considered, in addition to industrial R&D and university R&D, two more components of the geographically defined technological infrastructure: networks of companies from related industries and specialised business services. They found that all these four components together comprised a technological infrastructure which was advantageous for stimulating product innovations of companies on-site. Last but not least, the population size of regions was generally considered in the regression models to proxy the size effect of regions.

Compared to the research carried out in the US and in some selected European countries, econometric analysis on the same topic using Chinese data is scarce, though spatial academic spillover effects on corporate innovation performance should be expected to be pronounced for China as well. The traditional division of labour – universities and companies responsible for research and production respectively – and increasingly strong governmental support for intensifying university-industry linkages and for encouraging indigenous industrial innovation mean that it is increasingly advantageous for companies to engage in searching formal and informal academic support for their innovation activities (Gu and Lundvall, 2006; Eun, 2009). Li et al. (2010) analysed a provincial panel dataset from China to investigate the transfer of innovation capability from universities to companies. Two focus variables which they used to proxy the cooperation between universities and companies were the number of companies cooperating with universities and the amount of university R&D expenditure financed by companies. The former variable was found to affect corporate patenting performance positively at the 1% significance level, while the latter variable was ultimately omitted from the final model due to a problem with multicollinearity. Furthermore, the paper did not explicitly consider the geographic aspects of academic research. Thus, the finding provided only some implicit support that proximity to academic research may matter for corporate innovation performance in the case of China. [59] As additional caveat of the paper was that it did not take into account the time

[59] Li et al. (2010) found that the more companies were cooperating with universities, the more patents were created by companies in the same province. Assuming that effective cooperation requires fruitful

lag between innovation inputs invested and patents as innovation outputs created, nor did it deal with issues such as firm-level and provincial heterogeneity.

There are some studies investigating innovation activities of companies and/or total factor productivity in China using more sophisticated econometric methods (e.g. Hu et al., 2005; Jefferson et al., 2006; Hu and Jefferson, 2009). Their regression models were derived from the knowledge production function framework as well. However, their analysis was carried out at the firm level instead of at the regional level and the authors did not explicitly consider universities as potential knowledge sources for supporting companies' innovation activities. Rather, the focus was put on companies' own R&D efforts, external knowledge inputs either purchased (domestically and internationally) or transmitted through companies' exporting or foreign direct investment (FDI) activities and different firm characteristics such as ownership structure. Their findings indicate that firms' own R&D is highly significant for innovation as evidenced for Western economies. However, the omission of potentially important regional spillovers from universities to firms in these papers remains a shortcoming. Nevertheless, the positive effect of the firms' global engagement and organisational characteristics makes it clear that comparable variables (but at the regional level) need to be considered in a regression model for analysing the spatial spillover effects.

3.3 Data and Estimation Issues

3.3.1 Data

This paper aims to analyse whether there exist significant spatial academic knowledge effects on corporate innovation performance also for China. To do this, we apply the regional knowledge production function framework as applied in the related literature for the US and Europe (s. Section 3.2). For this purpose, our econometric analysis is based on a provincial panel dataset from 2000 to 2008. In total 30 provinces are considered. Tibet is excluded from the analysis due to limited data availability. Data inputs for the panel dataset were collected from different official statistical sources for various years.[60]

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communication and interactions between innovators from universities and companies, the positive finding in the paper may suggest the existence of a positive role of proximity for determining the potential academic spillover effect on corporate innovation performance.

[60] Innovation-related data were collected from the China Statistical Yearbooks on Science and Technology. Patent data of universities were collected directly from the Statistical Annual Reports of the State Intellectual Property Right Office of People's Republic of China. The number of universities and industrial entities at the city level for calculating the accessibility measures to investigate the spatial

Companies in China have mainly relied on their low-cost production advantage to gain a competitive edge over their competitors in the world market. However, with intensified global competition and the policy change of the Chinese government towards promoting product upgrading and higher value-added activities, companies in China are increasingly encouraged and/or forced to engage in more innovation activities. As a result, the number of patent applications filed by companies at the China's State Intellectual Property Office (SIPO) increased by about 27% annually from 2000 to 2008.[61] Almost half of these corporate patent applications, especially the invention ones, were filed by large and medium-sized industrial enterprises, although they just represented a small proportion of all companies in China (NBSC-CNSY, 2001-2009; NBSC-CNSYST, 2001-2009).[62] The high innovativeness of the large and medium-sized industrial enterprises and the availability of R&D data for these companies at the provincial level cause us to focus our further analysis on the large- and medium-sized industrial enterprises only. For the sake of simplicity we use the words 'companies' and 'corporate' patenting performance as synonyms for large and medium-sized enterprises and their patenting activities.

In 2008, these companies filed more than 122,000 patent applications.[63] This was ten times higher than the number of patent applications they filed in 2000. Most of the corporate patents were filed in the eastern region[64] of China (77% in 2000), while

effects of academic research were collected from the China City Statistical Yearbooks. Industry-level data used for calculating the industry concentration index were collected from annual statistical yearbooks of all provinces except for Tibet. Remaining data were collected from the China Statistical Yearbooks.

[61] There are three types of patents in China: invention patents, utility model patents, and external design patents. These three patents are different from each other in terms of how radical and novel is the commercial knowledge generated, the application requirements, the length of application processing time, and the length of protection term. According to the SIPO (2008), the application requirements for invention patents are most demanding and complicated compared to the requirements for the other two types of patents. Accordingly, the examination process for granting invention patents is more time-consuming but the protection term of such patents is longer than other two types of patents. More (intensive) research inputs in innovation activities are expected to be needed for realising invention creations suitable for being patented as invention patents than the inputs needed for other two technologically less demanding patent types. See Hanley et al. (2011) for more information.

[62] In 2008, 41% (46%) of all corporate patent applications (corporate invention patent applications) were filed by large and medium-sized industrial enterprises, which accounted for just 9% of all industrial enterprises above designated size in China. Industrial enterprises above designated size are those with annual revenue from principal business over 5 million RMB (NBSC-CNSY, 2009; NBSC-CNSYST, 2009). RMB is an abbreviation for the Chinese currency 'Renminbi'.

[63] Total numbers of corporate invention and non-invention patents as well as their R&D expenditure over the research period (2000-2008) are presented in Figure 3.A.1 in the appendix (Section 3.A).

[64] The 31 provinces in mainland China are usually grouped into three regions: the eastern (coastal), the central and the western region. The eastern region comprises 11 provinces: Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Liaoning, Shandong, Shanghai, Tianjin and Zhejiang. The western region comprises 12 provinces (Chongqing, Gansu, Guangxi, Guizhou, Inner Mongolia, Ningxia, Qinghai,

the corresponding shares of patent applications in the central region and in the least developed western region were just 14% and 9% in the same year. Over the research period, the distribution of the corporate patent applications across these three regions hardly changed, amounting to 78%, 12%, and 10% in eastern, central and western region in 2008, respectively. In contrast, the distribution of corporate patent applications at the provincial level in 2008 differed quite markedly from the corresponding proportion in 2000. For example, Guangdong – the pioneer province of China's economic reform – still ranked first as the province with the highest number of corporate patent applications in China, but its share in 2008 (27%) was much higher than that in 2000 (19%). Shandong – the province with the second highest number of corporate patent applications in 2000 – accounted for 18% in 2000 but only for 10% in 2008. As suggested in the literature (see Section 3.2), different amounts of innovation inputs proxied by, for example, R&D expenditure, are expected to be one of the major determinants for the diverging patenting performance. Guangdong indeed also ranked first among all provinces with respect to the R&D expenditure of companies in both years. Shandong which ranked second in this regard in 2000 was outperformed by other provinces in 2008, which was consistent with the development of corporate patenting activities over time (NBSC-CNSYST, 2001 & 2009).

Companies' patenting performance is additionally expected to be affected by how easily firms can interact with university researchers thereby making use of academic knowledge created by universities. For a long time, university research represented the only official research sector for the Chinese economy. Though nowadays official research is no longer restricted to universities, universities are characterised by an impressive record of patenting: universities applied for more than 30,000 invention patents in 2008, compared to less than 2,000 patents in 2000 (NBSC-CNSYST, 2001 & 2009).[65] In addition, the number of scientific articles universities published and had registered in well-known foreign referencing systems[66] in 2008

Shaanxi, Sichuan, Tibet, Xinjiang and Yunnan) and the Central region 8 provinces (Anhui, Heilongjiang, Henan, Hubei, Hunan, Jiangxi, Jilin and Shanxi).

[65] See Footnote 61 for more information about the three patent types in China. Driven by their focus on basic research, universities in China file more invention patent applications than the other two types of patents. In 2008, the number of utility model patent applications (external design patent applications) filed by universities amounted to less than 1/3 (1/6) of the number of academic invention patent applications. Total numbers of the three types of patents applied by universities over the research period (2000-2008) are presented in Figure 3.A.2 in the appendix (Section 3.A).

[66] This refers to the number of Chinese scientific papers taken by major foreign referencing system such as SCI (Science Citation Index), EI (Engineering Index) and ISTP (Index to Scientific & Technical Proceedings).

(more than 240,000) was also much higher than the number for 2000 (roughly 42,000).[67] Similar to the distribution change of corporate patent applications across provinces, the distribution of university research results in 2008 markedly changed compared to 2000. Though Beijing and Shanghai still ranked outstanding among all provinces with respect to both university research results, the relative weights in 2008 were lower than in 2000 (NBSC-CNSYST, 2002 & 2010).[68] When considering both the increase in the number of universities and the more equal distribution of universities across provinces in China over the research period (Bickenbach and Liu, 2011a), companies in 2008 had more scope to reach and interact with universities and gain an easier access to academic knowledge from universities than it was the case in the past. As a result, companies were in a position to profit more from considerably more accessible academic knowledge in 2008 than in 2000. This should entice a high propensity of firms for filing patents. Zhejiang, for example, ranked fourth with respect to the number of corporate patent applications filed in 2000, became the province with the second highest record of corporate patent applications in 2008. While companies themselves invested relatively more in R&D activities over the period, they may also have profited strongly from the rapid increase in invention patent applications filed by universities in Zhejiang (NBSC-CNSYST, 2001 & 2009).[69]

3.3.2 Estimation Issues

3.3.2.1 Baseline Estimation Model and the Accessibility Measure

This paper, in line with previous literature, derives its estimation model from the Griliches-Jaffe knowledge production function framework. The baseline model is as follows:[70]

$$\log P_{rt} = \alpha + \beta_1 \log(RD_{rt} C_{rt}^{\mu}) + \sum_{l=2}^{L} \beta_l \log X_{lrt} + \eta_r + \varepsilon_{rt}$$

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[67] Total number of academic journal publications as well as universities' R&D expenditure over the research period (2000-2008) are presented in Figure 3.A.3 in the appendix (Section 3.A).

[68] Universities in Shanghai (Beijing) filed about 16% (16%) of all academic invention patent applications in 2008, compared to 25% (19%) in 2000. Regarding the publication records, Beijing (Shanghai) accounted for 'only' 20% (10%) of all scientific papers registered in the foreign referencing systems in 2008, compared to 30% (12%) in 2000.

[69] R&D expenditure of companies in Zhejiang accounted for about 4% of all industrial R&D expenditure in China in 2000. The share increased to 7% in 2008. The increase in the share of invention patent applications filed by universities in Zhejiang was even stronger, from 3% of all invention patents applied by universities in 2000 to 9% in 2008.

[70] A summary of the basic statistics for variables used in the estimation (basic and extended) models is provided in Table 3.A.1 in the appendix (Section 3.A).

$$= \alpha + \beta_1 \log RD_{rt} + \beta_1 \mu \log C_{rt} + \sum_{l=2}^{L} \beta_l \log X_{lrt} + \eta_r + \varepsilon_{rt} \quad (3.1)^{71}$$

where *r* represents our regional observation unit – Chinese province. The number of patent applications filed by companies (*P*)[72] in province *r* in year *t* is expected to be positively determined by the size of the firms' R&D expenditure (*RD*). Assuming the existence of a positive academic spillover effect on corporate patenting, companies in one province with easier access (*C*) to universities than companies in the other province are expected to be capable of transforming their R&D inputs into positive patenting results more productively than their counterparts. X_{lrt} are control variables which are not focus variables in our study but are expected to also affect companies' innovation propensity and performance as shown in the literature.[73] Since companies may rely on innovation inputs to different degrees to carry out various innovation outputs, we consider, in addition to the number of total patent applications filed by companies in a province, two more disaggregated categories[74] as additional dependent variables: invention patents and non-invention patents.[75] To cope with the potential problem of unobserved regional heterogeneity, η_r is considered as a provincial fixed effect in the regression model. ε_{rt} is the error term.

$$\log P_{rt} = \alpha + \beta_1 \log RD_{rt} + \tilde{\mu} ACCE_{rt-1} + \sum_{l=2}^{L} \beta_l \log X_{lrt} + \eta_r + \varepsilon_{rt} \quad (3.2)$$

The variable *C* in Eq.[76] (3.1) is a general term used to represent companies' accessibility to university research. In contrast, the variable *ACCE* in Eq. (3.2) is a measure we construct based on the logsum indicator to measure the average university

[71] In this dissertation the abbreviation 'log' is synonym for the abbreviation 'ln'. Both mean the natural logarithm.

[72] Though patent statistics are, due to some inherent caveats, not the best economic indicators which can be used to proxy new knowledge produced (e.g. Pakes and Griliches, 1980a & 1980b; Griliches, 1990), these are the only statistics available in China at the provincial level which allow us to disaggregate the overall patent statistics into two categories by technical and technological requirements. This advantage enables us to investigate whether companies' proximity to universities may matter differently for corporate patenting activities requiring different levels of techniques and technologies.

[73] One control variable is considered directly instead of its log format in the regression model due to its statistical nature. More information about the control variables considered is provided in the next paragraphs.

[74] As indicated in Footnote 61 there are three patent types in China: invention patents, utility model patents, and external design patents. Here we group the two technologically less demanding patents (utility model patents and external design patents) together under the category 'non-invention patents'.

[75] Innovation output variables are presented in log transformation in the estimation models. Since there are two zero entries (of 270 observations in total) with respect to the number of corporate non-invention patents at the provincial level, we calculate the corresponding log variable in this case in the following way, consistent with Feldman and Florida (1994): ln(P_ninv) = ln[exp(1)*(1+P_ninv)] to allow us to have a balanced dataset for analysis.

[76] Eq. means Equation.

accessibility for companies in the province *r* at the time *t*. Since the variable is an interval-scaled variable, we consider the constructed variable instead of its log transformation in our estimation model. The corresponding coefficient should thus be interpreted as the percentage change of corporate patenting results with respect to a one unit improvement in companies' accessibility to universities (semi-elasticity). In contrast, the other coefficients (βs) can be, if not otherwise mentioned, directly interpreted as elasticities of corporate patenting results to a 1% increase in R&D expenditure or in other covariates.[77]

The accessibility measure at the provincial level, *ACCE*, is constructed based on city-level statistics as follows:

$$\bar{d}_{it} = -(1/\gamma)\log[\sum_{j=1}^{J} NO_{jt}^{uni} \exp(-\gamma DIS_{ij})] \tag{3.3a}$$

$$\bar{d}_{rt} = \sum_{i\in r} \bar{d}_{it} (NO_{it}^{ind} / \sum_{i\in r} NO_{it}^{ind}) \tag{3.3b}$$

$$ACCE_{rt} = -\bar{d}_{rt} \tag{3.3c}$$

As the first step (Eq. (3.3a)), we calculate the average distance to university in kilometres ($\bar{d}_{it}$) from a representative company's point of view in city *i*. Theoretically, this company can access universities not only in its own city but also in all other cities in China. Here we use the variable DIS_{ij} to measure the kilometre distance between the company in city *i* and the universities in city *j*.[78] Under the strong but practical assumption[79] that universities are indifferent from each other with respect to their research quality, companies able to access a higher number of universities (NO_{jt}^{uni}) are expected to be able to access a higher number of university research outcomes. Universities located in cities farther away from the company (city *i*) would, however, contribute less to the overall potential academic knowledge for the company.[80] The scale of the distance decay effect would accordingly depend on the size of the distance decay parameter considered (γ). Assuming γ equal to 0.05 km^{-1} as our base value, this

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[77] The estimated coefficient of the control variable which is considered directly in the regression model (instead of its log form) should also be interpreted as a semi-elasticity instead of as an elasticity.

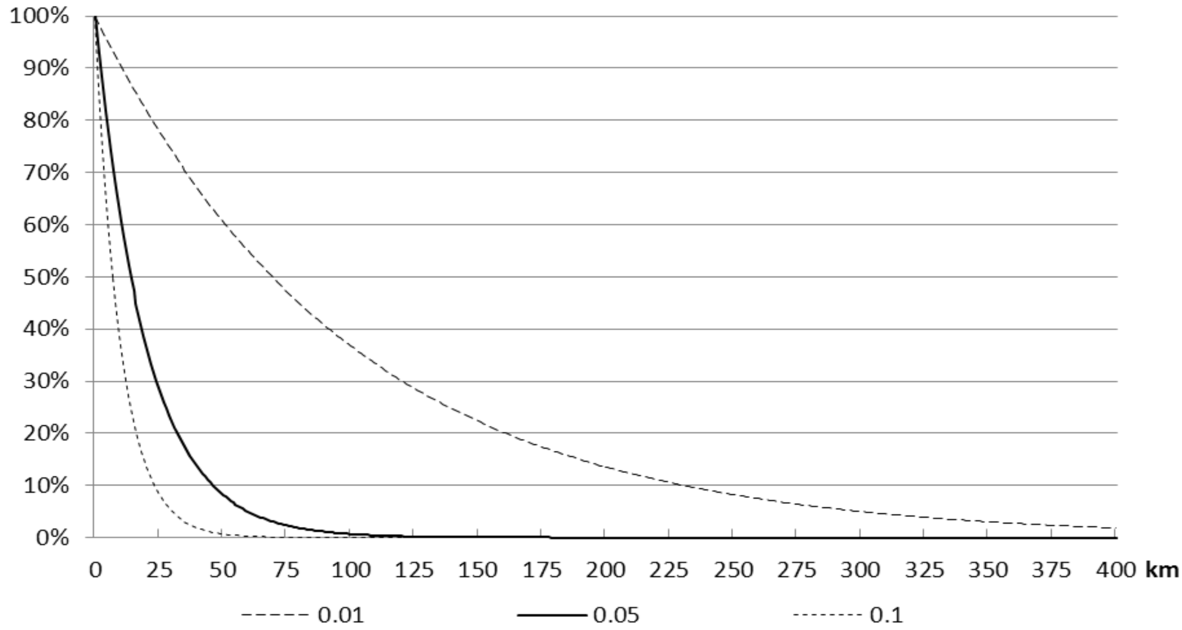
[78] The distance here refers to the great-circle distance between two cities which is measured based on the geographical latitude and longitude of each pair of cities considered.

[79] The assumption would be relaxed for robustness checks (Section 3.3.2.2).

[80] See Schulz and Bröcker (2007) and Spiekerman and Wegener (2007) for short summaries of different accessibility measures. See Ben-Akiva and Lerman (1985) for more information about the underlying concept of the logsum accessibility measure, namely the utility maximising behaviour of individuals through making their multidimensional choices among alternative goods.

means that the potential contribution of a university located one more kilometre away from the company would decrease by 5%. Reasons for assuming γ equal to 0.05 km^{-1} as our base value are twofold. Firstly, assumed γ equal to 0.05 km^{-1}, the potential contribution of a university located 13.8 kilometres away from the company (city *i*) would decrease by 50% and its potential contribution almost disappears (only 0.1% left) if it located more than 138 kilometres away (Figure 3.1). This is in line with our case study finding in Hong Kong in Fall 2007 that senior managers of Hong Kong electronics firms[81] are ready to spend two and a half hours on average to travel from Hong Kong to Guangzhou to discuss with their local managers and business partners in Guangzhou. The great-circle distance between Hong Kong and Guangzhou is about 131 kilometres and the Hong Kong managers are less willing to travel farther away for face-to-face communications on a daily base. Secondly, the concept of the accessibility measure introduced above is used in several empirical transportation economics literature (e.g. Bröcker, 1998; Bröcker et al., 2002; Johansson et al., 2002; Andersson and Ejermo, 2005; Spiekerman and Wegener, 2007; Niebuhr, 2008). Closely related to our research subject, Andersson and Ejermo (2005) constructed their accessibility measure based on the same concept to analyse how accessibility to knowledge sources may affect firms' innovativeness in Sweden. In their analysis they call γ a time sensibility parameter and set it as 0.1 min^{-1} for intraregional interaction and 0.017 min^{-1} for interregional interaction, based on the information they can obtain from Åberg (2000) and Hugersson (2001). For simplicity, assumed a constant driving speed of 60 km/h, the parameters they used correspond to 0.1 km^{-1} and 0.017 km^{-1}, respectively. In our analysis we do not differentiate the intraregional interaction from the interregional interaction. The base value we use (0.05 km^{-1}) is roughly equal the average value of these two parameter values. For robustness check we also set our distance decay parameter equal to 0.1 km^{-1} and 0.01 km^{-1}, respectively.

[81] In 2007 we conducted a company survey in Hong Kong. Data obtained from the questionnaire survey is used for the analysis in Chapter 4. In addition to the survey which addressed Hong Kong electronics small- and medium-sized enterprises with operation in the Pearl River Delta in Guangdong, we conducted several in-depth interviews with large electronics firms in Hong Kong, several industrial associations, Hong Kong Science Park, various departments of the Hong Kong Applied Science and Technology Research Institute and Hong Kong Innovation and Technology Commission for more background information.



Note: Own presentation.

Figure 3.1 – Potential Contribution of a University Located in Different Kilometres Away from City *i* Compared to a Reference University in City *i*
(γ =0.01 km^{-1}, 0.05 km^{-1}, 0.1 km^{-1})

In this way, we calculate the average distance to university for companies in all existing cities in China.[82] A representative company in city *i* with a smaller average distance is interpreted to have a higher scope to access to universities. As the second step (Eq. (3.3b)), we calculate the province-level average distance to universities ($\bar{d}_{rt}$) as a weighted average of city-level average distances using city-level share of companies as weights. NO_{it}^{ind} is the number of industrial companies located in city *i* at the time *t*.[83] The reason for using the weighted average is the unequal distribution of

[82] The number of cities (prefectural level cities) was different in some years due to upgrading of some county-level cities to prefectural level cities. Data regarding county-level cities were much more limited. Thus the statistics at the prefectural level were the most disaggregated ones which we could use for calculating the accessibility measure. In the paper, we use the term ‘cities’ as synonym for ‘prefectural level cities’. In total there were 286 cities in the years from 2004 to 2008, while there were only 284, 278, 267, 262, and 236 in the years back from 2003 to 1999, respectively (NBSC-CCSY, various years).

[83] Due to limited availability of data on the number of large and medium-sized industrial companies across cities over time, we use the number of industrial enterprises as proxy which was the best statistics we could obtain for our purpose here. At the provincial level, both variables are significantly and highly correlated over the research period (0.94 at the 1% significance level). Before 2007 industrial statistics provided data of state-owned enterprises and non-stated-owned enterprises with annual revenue from principal business over 5 million RMB. Since 2007 such statistics provided data of industrial enterprises with annual revenue from principal business over 5 million RMB. Comparing the definition of industrial enterprises covered before and after 2007, the only difference was the explicit indication of the inclusion of state-owned enterprises in the related statistics. But since state-owned enterprises are mostly large in size and are characterised by high revenue compared to non-stated-owned companies in China, industrial

companies across cities with different levels of access to universities. We expect that the average province-level distance to universities to be lower, i.e., higher accessibility, if relatively more companies are located in cities with higher accessibility to universities but not in cities with lower accessibility to universities. Similar to its city-level counterpart, the province-level average distance to universities is measured as an interval-scaled variable. The distance between two such values but not the value itself is meaningful for interpretation. As the final step to derive our accessibility measure (Eq. (3.3c)), we multiply the province-level average distance by (-1). On the basis of the calculated *ACCE*, the provincial university accessibility is no longer inversely ranked. Instead, if companies have higher accessibility to university in the province *r*, the corresponding *ACCE* would be also higher in value than that in the provinces where companies have lower accessibility to university. Assuming a potential time lag between the foundation of universities and the potential positive effects on corporate patenting performance, the *ACCE* is represented in Eq. (3.2) by its one-year lag. Based on our expectation of positive academic research effects, the corresponding coefficient $\tilde{\mu}$ is expected to be significantly positive.

In addition to companies' R&D efforts and their accessibility to universities, different firm characteristics are expected to influence companies' willingness for and their performance in patenting activities. We consider four variables to control for firm heterogeneity at the regional level. First, we consider the industrial concentration of companies (*INDCON*) within the province based on the number of companies in 38 industrial sectors[84], using the concept of the GINI index. We expect a significantly relevant Marshall externality (Marshall, 1920) where the concentration of companies in few industries in a province facilitates knowledge transfer and knowledge diffusion among companies. This, in turn, further spurs the knowledge creation and patenting activities of companies in that province (e.g. Feldman and Florida, 1994). The second variable is also an industry-related variable (*ICT*), which is measured as the share of

statistics since 2007 still covered most of these state-owned enterprises. Thus, the simplification in the definition of industrial enterprises in statistics is not expected to be a severe problem for our analysis.

[84] Data of industrial enterprises, but not just data of large and medium-sized companies, are used here. We expect that companies considered in the analysis (large and medium-sized companies) may not only profit from the concentration of large and medium-sized companies in few industries but from the corresponding concentration of industrial enterprises in general. In total 38 industrial sectors are considered. Since 2003 a new industry classification has been applied. To enable us to calculate the industrial concentration index for the earlier years, we adjust the old industry classification to the new one. The sectors which were not continuously specified over time are reclassified to 'other sectors'. Companies from these reclassified sectors accounted for just a minority of the whole companies.

companies from the ICT industry[85]. This variable attempts to capture the high preference and tendency of ICT firms for patenting activities (Eberhardt et al., 2011). The other two firm covariates deal with companies' potential advantage in more easily obtaining knowledge and technologies for innovation from foreign market and investors through either their engagement in foreign trade activities and/or through their on-site confrontation with more foreign companies (e.g. Criscuolo et al. 2005; Wagner, 2006; Hu and Jefferson, 2009). The former one is embodied in a variable called *OPEN* which is measured as the ratio of trade volume to GDP, while the latter one *FOR* based on the share of foreign companies[86] of a province.

Last but not least, since our analysis is based on regional data and uses provinces as the observation unit, we consider two more variables to control for observable regional characteristics. The first variable – population size of the province (*POP*) – was considered in most of the related literature introduced above (e.g. Jaffe, 1989; Feldman and Florida, 1994) to control for size differences between provinces. Region size is expected to positively affect the number of patent applications filed. A positive effect is also expected with respect to the second variable – the relative size of high-educated population of the province (*HEDU*)[87] – which was also considered by Bottazzi and Peri (2003). Highly educated people support a rapid transmission of knowledge among individuals. The greater the relative size of the regional population of highly educated individuals, the higher the expected volume of regional corporate patenting. The remaining unobserved regional heterogeneity is dealt with by considering a provincial fixed effect variable in our regression model. All control variables apart from the industrial concentration measure are presented as logs in the regression models.[88]

[85] The ICT (information and communication technologies) industry refers to an industry producing communication equipments, computers and other electronic equipments. For this variable we use the same data sources as those for being used to calculate the variable *INDCON*.

[86] Data of all industrial enterprises, not just data of large and medium-sized companies, are used here. We expect that companies considered in the analysis (large and medium-sized companies) may not only profit from the presence of foreign large and medium-sized companies but from the presence of foreign companies in general. Data about companies above the designated size cover a much larger part of (foreign) companies in China, thus consistent with our analysis purpose here.

[87] Data of *HEDU* in 2001 are average values calculated from the data of *HEDU* in 2000 and 2002, since the base data needed to calculate *HEDU* in 2001 are not available.

[88] Since the ICT share was equal to zero in 8 of 270 observations, we calculate its corresponding log format in the following way: ln(ICT) = ln[exp(1)*(1+ICT)] to have a more balanced dataset for analysis.

3.3.2.2 Further Estimation Issues

For all regression models estimated we separately consider three different variables to proxy regional industrial innovation performance, i.e., corporate knowledge produced at the regional level: total number of corporate patents (*P_all*), total number of corporate invention patents (*P_inv*) and total number of corporate non-invention patents (*P_ninv*). The differentiation of invention patents from non-invention patents enables us to investigate, in particular, whether there are differing academic spillover effects on industrial innovation performance when the knowledge produced is characterised by different levels of novelty and/or technical requirements.

Variables which are considered to be potential determinants for regional industrial innovation performance in Eq. (3.2) enter the estimation sequentially. We start by considering only the two key variables, namely companies' R&D expenditure (*RD*) and their accessibility to universities (*ACCE*). In the subsequent regressions, we also include the second group of determinants, namely the two industry-related variables (*INDCON* and *ICT*) and the two region-specific variables (*HEDU* and *POP*). We consider the first two variables to control for observed industry-related firm heterogeneity and the latter two to control for observed regional heterogeneity. Lastly, we introduce the variables *OPEN* and *FOR* into our regression models to control for companies' differing global engagement to take into account potential regional effects for China resulting from the external world on industrial innovation performance.

We estimate the regression models with both Within-estimator and Random Effect estimator (RE-estimator).[89] To investigate whether the Within-estimator or RE-

[89] We apply panel OLS techniques instead of count data model techniques to estimate the knowledge production functions in this chapter. Count data model techniques (e.g. Poisson, and Negative Binomial models) are usually used if the event is considered as a rare event and "the sample is concentrated on a few small discrete values, say 0, 1, and 2" (Cameron and Trivedi, 2005: 666). Datasets analysed with count data model techniques are usually characterised with a great proportion of observations with zero counts. Cameron and Trivedi (2005) summarises a list of studies applying count data models for analysis, showing that the proportion of observations with zero counts can be as high as 90%. As regards knowledge production functions, count data model techniques are usually used for estimating knowledge production functions if individual firms or small regions are taken as observation units and thus zero counts are frequently observed (e.g. Fritsch and Slavtchev, 2007). In contrast, if zero counts are not frequent observations, normal distribution is assumed and (panel) OLS techniques are applied (e.g. Anselin et al., 1997; Fisher and Varga, 2003) In our regional analysis, Chinese province is our observation unit and no province is labeled with zero counts of industrial patents for each year of our research period. (Only when separating industrial patents into invention and non-invention patents, two of the 270 observations are zero in non-invention patents. See Footnote 75 for more information about the transformation technique applied to build the variable P_ninv in log.) In 2008, the number of patents applied by firms in Guangdong amounted to 33,144 patents (maximum). Firms in Qinghai in the same year were least active in patenting, but they still applied for more than 80 patents. The mean of the number of patent applications in 2008 was 4069 patents. It is thus inappropriate to assume the provincial patenting a rare event with amounts of zero counts. In addition, since the mean is large over the whole

estimator is more preferred, we run statistical tests after estimating the models with the two estimators. In addition, in case of significant within-panel correlation, we estimate our models using the cluster-robust VCE estimators (e.g. STATA, 2007).

We apply two methods to deal with potential endogeneity problems with respect to companies' R&D engagement.[90] Firstly, we deal with endogeneity problems by representing the variable (*RD*) in terms of its lagged value. Secondly, we re-estimate our full baseline models with instrumental variable estimation techniques. We use company size (measured as sales) and company's capital use relative to its production outputs – both at the provincial level – as instrumental variables for the *RD* variable (e.g. Bound et al., 1984) since they are expected to affect companies' success in patenting through their strong impact on firms' R&D engagement but not through other channels.

More concretely, companies with higher sales revenue in the past are expected to be more capable in engaging in large-scale, long-term R&D activities with potential innovation success being worth to be patented. In 2008 companies' R&D expenditure amounted to, on average, 1.03% of their sales revenue of 2007 (NBSC-CNSYST, 2008 & 2009). The correlation coefficient between companies' R&D expenditure in 2008 at the province level and their corresponding sales revenue in 2007 was as high as 0.985. This gives some support for our expectation that companies' R&D expenditure is strongly determined by the financial resources which companies have accumulated through positive sales outcomes in the past. Although one may expect that companies with higher sales revenue may also invest more in acquiring technologies from external sources such as universities and universities were found to be significantly relevant knowledge sources, in addition to firms' R&D activities, for their patenting activities (See Chapter 2 and Section 3.2), this expectation of a strong relation between firms' financial situation and their willingness for sourcing knowledge from universities is less supported by related statistics. Take again the year of 2008 as example. In this year companies spent on average only an extremely small share of their sales revenue of 2007 (0.06%) for acquiring technologies from all external but domestic sources, including universities (NBSC-CNSYST, 2008 & 2009). This share was only about one twentieth of the share of sales revenue which companies invested in their own R&D activities, showing a low relevance of external knowledge sources as a whole for the

research period, it follows from the central limit theorem that the distribution of the variable is approximately normal (e.g. Wooldridge, 2002). Thus, we apply panel OLS for our analysis in this chapter.

[90] For example, one may expect that companies' willingness to invest more in R&D depends on their success in producing new knowledge and new patents in the past.

innovation activities of our focus companies. Moreover, the external sources considered in the statistics include not only universities but also non-university innovators and according to our firm-level analysis in Chapter 2 when it comes to acquiring innovation-related technologies and know-how from external sources, universities have been perceived by Chinese firms as least relevant sources compared to other knowledge sources. Against this background, we are convinced that firms' sales revenue in the past can only significantly affect their success in patenting through their strong influence on their own R&D engagement but not on their increasing willingness for sourcing knowledge from universities.

Differently, the reasoning why firms' capital-to-output ratio is supposed to be a valid instrument as well is more forward-looking. Companies in China have been responsible for labour-intensive and low value-added production activities for a long time. Increasing capital intensity for production gives some hints for companies' willingness to undertake a structural change to move up the value chains to take over more capital-intensive work to sustain their market competitiveness and thus some hints for their willingness to deal with new market challenges with a more risk-taking attitude. Such risk-taking attitude is strongly required when companies are forced or encouraged to decide on investing in large-scale R&D activities, outcomes of which cannot be foreseen in advance. Risk-loving companies are expected to be more willing in engaging in such costly R&D activities with high outcome uncertainty. Instead, firms' risk-taking attitude is not expected to be significantly relevant for their decision for sourcing existing, thus less uncertain, innovation outcomes from others, especially from universities, which otherwise were found to be relevant innovation inputs for firms' patenting success as well. As a result, we expect that companies with increasing capital intensity are more risk-loving in nature which can thus have positive influence on their patenting results through their stronger willingness to engage in large-scale long-term R&D activities bounded with high risks and outcome uncertainty. We carry out statistical tests to investigate the relevance and the exogeneity of the instrumental variables considered. We ultimately investigate whether endogeneity problems indeed restrict the direct use of the *RD* variable. We apply Moran's I test statistics on the calculated error terms following the instrumental variable estimation to investigate the presence of significant spatial autocorrelation problems.

Moving to our second focus variable, we alter some features of the original *ACCE* variable (Eq. (3.3)) and consider these alternative *ACCE* variables in our regression models to check the robustness of its effect on regional industrial innovation performance. First of all, we use alternative values of the distance decay parameter (γ) to calculate the *ACCE* variable: 0.01 km^{-1} and 0.1 km^{-1}. With γ set equal to 0.01 km^{-1} instead of our base value 0.05 km^{-1} the contribution of a university, located one more kilometre away from the company, to academic knowledge potential relevant for companies would decrease by only 1% rather than 5%. In contrast, with γ set equal to 0.1 km^{-1} this decrease doubles from 5% to 10%. By considering different levels of the distance decay parameter, we aim to check whether our findings are strongly affected by the predetermined level of the distance decay parameter. Last but not least, we expand our *ACCE* variable by adding the quality aspect of university research into the construction of the variable, thus slightly moving away from our simple assumption above that universities in China are equally strong with respect to their research capability, making our *ACCE* variable more appropriate for reflecting firms' access to the pool of 'relevant' academic knowledge.

We apply the following two quality concepts to calculate quality-adjusted *ACCE* variables for analysis. The first quality concept is based on the provincial ranking of universities according to their research quality in terms of the number of invention patent applications filed by the universities. This concept consists of the following three steps:

$$\bar{d}_{it}^{a1} = (-\,1/\gamma)\log[\sum_{j=1}^{J}(NO_{jt}^{uni}\exp(-\delta QR_{rt}))\exp(-\gamma DIS_{ij})] \quad (3.4a)$$

$$\bar{d}_{rt}^{a1} = \sum_{i\in r}\bar{d}_{it}^{a1}(NO_{it}^{ind}/\sum_{i\in r}NO_{it}^{ind}) \quad (3.4b)$$

$$ACCE_{rt}^{a1} = -\bar{d}_{rt}^{a1} \quad (3.4c)$$

The major difference between this quality concept and the baseline concept introduced above (Eq. (3.3a)-(3.3c)) is the exponential term '$\exp(-\delta QR_{rt})$'[91] added into Eq. (3.4a) to calculate the quality-adjusted average distance of a company in city *i* to 'relevant'

[91] This exponential term is added to take into account the potential impeding effects resulted by unviersity quality difference on firms' willingness to interact with universities, following the original concept of the logsum indicator. In the related literature, the logsum indicator is usually used for analysing transportation-related issues, and thus the impeding effects considered are normally driven by geographical distance or time distance. To the best of our knowledge the additional consideration of university quality difference in constructing the city-level quality-adjusted accessibility measure as presented in Eq. (3.4a) is new to literature. Our decision for the base value of the quality decay variable as introduced below is supported by the relative quality difference among universities in China from the Chinese government's point of view (see Footnote 93 for more information).

universities ($\overline{d}_{it}^{a1}$). This quality-adjusted average distance replaces the original average distance in the second and third step ((Eq. (3.4b) and (3.4c)). The variable QR_{rt} refers to the quality ranking of universities by province from zero to 29 with decreasing number of invention patent applications filed by universities in each province. Universities with a better quality ranking contribute more towards the potential of relevant university research for companies, the assumption being that universities from the same provinces are of the same quality. [92] The effect of quality differentials between university research on corporate patenting is reflected in the quality decay parameter (δ). A positive value of δ means that only universities with the best quality will be counted fully as relevant universities for companies, while universities with lower quality will be counted in Eq. (3.4a) as if fewer universities existed. We assume δ equal to 0.01 rank^{-1} as our base value. This implies that universities with a quality of one level lower than the best ones are considered as if there were only 99% of the existing universities relevant for companies instead of the full population of universities, assuming the same geographic distance from companies to the best universities and to the universities with a one level lower quality. In the extreme case, universities with the lowest quality level are considered, under the same assumption of the quality decay parameter, as if there are only 75% of universities of the existing universities are relevant for companies. This is consistent with the relative distribution of the priority universities across Chinese provinces which have been selected under the ‘211 Project’ to obtain preferential financial support from the Chinese central government for further quality improvement. [93] To check robustness, we also consider values of the quality decay parameter equal to 0.005 rank^{-1} and 0.05 rank^{-1}, respectively.

[92] Note that we only have provincial panel data instead of city panel data for measuring university research quality.

[93] The ‘211 Project’ is one of the two major projects of the Chinese central government to encourage Chinese universities to further improve their teaching and research quality. (The second project called ‘985 Project’ considers 39 universities only and focuses more on improving Chinese universities’ research position worldwide.) Under the ‘211 Project’ the Chinese government, based on the developing potential of the universities, has selected 112 universities from all provinces as priority universities of the 21st century which should obtain governmental financial support for further quality improvement. In 2008, 10 of the 66 universities in Shanghai (ranked first with respect to the number of university invention patents) were labelled as such priority universities (in relative term: 15%). In the same year, only one of the nine universities in Qinghai (ranked lowest with respect to the number of university invention patents) was selected as the priority university under the ‘211 Project’ (in relative term: 11%). This implies as if only 73% of universities in Qinghai (11% divided by 15%) are of comparable quality as universities in Shanghai. This is consistent with the 75% obtained from exp(-0.01*29) under the assumption that the base value of the quality decay parameter is equal to 0.01rank^{-1}.

Compared to the first concept, the second quality concept takes the variation of provinces in the number of invention patent applications filed by universities into account more directly. The first step of the second concept is to calculate the quality-adjusted average distance of a company in city *i* to universities in China as follows:

$$\bar{d}_{it}^{a2} = (-1/\gamma)\log[\sum_{j=1}^{J} QL_{rt}(NO_{jt}^{uni} / \sum_{j \in r} NO_{jt}^{uni})\exp(-\gamma DIS_{ij})] \qquad (3.5)$$

This implies that what matters for companies as academic knowledge is not merely the distribution of universities, but the distribution of invention patent applications filed by universities across cities. The new variable QL_{rt} refers to the number of invention patent applications filed by universities in province *r* at the time *t*. Given the same number of universities existing in city *j1* and city *j2*, both located at the same distance from a company in city *i*, universities in city *j1* provide more academic knowledge for that company than universities in city *j2* if the number of invention patent applications allocated to the universities in city *j1* is higher than that in city *j2*. As above, we assume that universities from the same province are of the same quality, indicating that the number of invention patent applications allocated to universities in each city is determined by the city's share of universities in the same province in addition to the total number of provincial academic invention patent applications. The quality-adjusted average distance obtained, $\bar{d}_{it}^{a2}$, replaces the corresponding $\bar{d}_{it}^{a1}$ in Eq. (3.4b) and (3.4c) thereby deriving the quality-adjusted accessibility measure as captured in our covariate ($ACCE_{rt}^{a2}$).

To check robustness we consider the number of published academic journal articles[94] and the amount of university R&D expenditure as alternative measures of university quality.[95] These different variables to proxy academic knowledge additionally help us investigate whether proximity of companies to academic knowledge embodied in academic invention patents matters more for corporate patenting than the proximity to academic knowledge embodied in journal articles. The intuition here is that information disclosed in academic journal articles might be more complete and more comprehensively explained to readers. This would help reduce the need to intensively communicate with university researchers. Last but not least, the difference in the role of proximity to academic outputs for corporate patenting and the

[94] See Footnote 66 for information about the foreign referencing systems considered here.

[95] Different variables to proxy university quality are also considered in applying the first concept to calculate the quality-adjusted accessibility measure for robustness checks.

role of proximity to academic inputs can be better explored. In most studies reviewed above academic research was proxied by university R&D expenditure instead of university innovation outputs. However, university innovation outputs may be more relevant than university R&D inputs for corporate patenting due to highly uncertain outcomes of the university R&D processes.

3.4 Estimation Results

The estimation exercises described in Section 3.3.2 can be summarised in the following five subsequent steps. Firstly, we start with estimating the baseline models with different sets of explanatory variables using both Within- and RE-estimators. Secondly, we deal with the potential endogeneity with respect to the industrial R&D (*RD*) based on instrumental variable analysis. Thirdly, we use alternative values of the distance decay parameter to check the robustness of our main findings. Fourthly, we move from the base accessibility measure to quality-adjusted accessibility measures to take into account the quality difference in university research in the analysis. Two quality concepts are applied to construct these measures. Finally, to check the robustness of the findings regarding the quality-adjusted accessibility measures we use alternative values of the quality decay parameter and three different variables to proxy the university quality. We present the results of the corresponding estimation exercises in sequence in this section.

Table 3.1 displays three groups of the baseline estimation results according to the three different types of companies' innovation outcomes at the provincial level: their total patent applications (Col.[96] (1) – (3)) and at a more disaggregated level their invention patents (Col. (4) – (6)) and their non-invention patents (Col. (7) – (9)). Due to significant within-panel (serial) correlation[97], we applied cluster-robust VCE estimators in estimating all regression models. We present estimation results based on the fixed effect regression models only, since random effect models are less preferred after running the statistical tests[98] to compare both models. Test results significantly reject the hypothesis of no systematic difference in estimation results from both models (at the 1% significance level).

[96] Col. means Column.
[97] We implement a Wooldridge (2002) test for serial correlation in the idiosyncratic errors in linear panel data models.
[98] We run a test of overidentifying restrictions (Sargan-Hansen Test Statistic) instead of the Hausman test, since the former one is more suitable for cases using heteroskedasticity- and cluster-robust estimators. See Schaffer and Stillmann (2010) for a detailed discussion.

For all three groups of the results, the explanatory variables are introduced sequentially as explained in Section 3.3.2. Our first key variable – companies' own R&D expenditure (*RD*) – is found to play a significant and substantial role for companies' success in innovation across all estimation models. The finding of a strong role of companies' own R&D for their patenting activities is consistent with our findings in Chapter 2 based on the firm-level analysis for the PRD in China. This finding is as well in line with most of the studies based on the comparable regional knowledge production framework, e.g. Jaffe (1989), Anselin et al. (1997), Piergiovanni and Santarelli (2001), Fischer and Varga (2003) and Barrio-Castro and Garcia-Quevedo (2005) introduced in Section 3.2. Total corporate patenting outcomes respond to a 1% increase in R&D expenditure by between 0.83% and 0.95%, depending on the sets of explanatory variables considered. Companies' own R&D expenditure is, as expected, much more relevant for companies' success in invention patenting which requires higher and more sophisticated technical and technological standards than for their success in non-invention patenting. A 1% increase in companies' R&D expenditure induces a roughly 1% increase in invention patent applications and a 0.8% increase in non-invention ones filed at the provincial level.

	P_all			P_inv			P_ninv		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
RD	0.946***	0.820***	0.833***	1.124***	0.978***	0.966***	0.922***	0.804***	0.819***
ACCE	0.013***	0.008***	0.008***	0.007*	0.002	0.001	0.010***	0.006*	0.006**
INDCON		0.043*	0.044*		0.029	0.029		0.049*	0.052**
ICT		0.300**	0.257**		0.261*	0.278**		0.295**	0.204**
HEDU		0.307**	0.240		0.457**	0.487**		0.241*	0.106
POP		1.139	0.901		1.664	1.789		0.721	0.276
OPEN			-0.099			0.073			-0.148
FOR			0.391*			-0.189			0.764***
Obs.	270	267	267	270	267	267	270	267	267
F	170.13***	80.28***	83.28***	203.07***	146.36***	150.38***	155.66***	65.92***	75.04***
R-sq	0.761	0.775	0.780	0.750	0.762	0.763	0.675	0.685	0.703

Notes: 1. All columns: fixed effect model using robust cluster VCE estimator. 2. All variables except for *ACCE* and *INDCON* are in log in the estimation model. *ACCE* in one-year lag is considered in the regression models. All coefficients are expected to be positive. Hypotheses are tested based on one-tailed tests. ***/**/* refer to 1%/5%/10% significance level. _cons is not shown here.

Table 3.1 – Estimation Results of the Baseline Regional Knowledge Production Function by Patent Type (Baseline Model Estimation Using Panel OLS)

Compared to the strongly positive role of companies' own R&D expenditure for their patenting results, the relevance of companies' proximity to universities is found to be weaker and not always significant as found in the seminal work of Jaffe (1989) for the US states. A one kilometre reduction in their provincial average distance to a university, i.e., one unit increase in the ACCE indicator, leads to about a 0.8% to 1.3% increase in total corporate patent applications filed at the provincial level. Comparing the estimation results for invention patent applications versus non-invention patents, we find that companies' proximity to universities matters significantly only for their non-invention patenting results but not for the technologically more demanding invention patenting results. The finding that companies' proximity to universities matters differently for companies' different types of patenting results is especially worth being noted here. Previous studies as presented in Section 3.2 did not differentiate patents into different types according to their technological requirements. Accordingly, our findings may suggest, on the one hand, that universities, although they have been mainly responsible for research activities in China for a long time, can only provide technologies and know-how relevant for technologically less demanding innovation activities. Thus, companies located closer to universities may benefit more from such academic knowledge in terms of better non-invention patenting results.

On the other hand, these findings may suggest that, when it comes to technologically more demanding patenting, companies may search for advanced academic knowledge from higher quality universities, irrespective of the location of the universities. Whether university quality indeed plays a role is investigated by later estimation models using quality-adjusted accessibility measures. Still our finding that companies' proximity to universities matters significantly for their patenting activities in general and for their non-invention patenting in particular provides some evidence for the existence of spatial academic effects in China as well on the one hand and some support, due to the *ACCE* variable used, for the irrelevance of urban or provincial boundary as impediments against the spatial academic effect as found in Anselin et al. (1997) on the other hand.

Regarding the set of control variables considered in the estimation models, we find in most cases some empirical support consistent with our expectation. A higher share of ICT companies in a province (*ICT*) drives the corporate patenting results of the province – both invention and non-invention patents – strongly upwards. This finding is consistent with our expectation derived from the findings of Eberhardt et al. (2011) that ICT firms have normally higher preference and tendency for patenting activities. We generally find a significantly positive role of industrial concentration (*INDCON*) for provincial patenting, in line with Marshall externality arguments and findings of

Feldman and Florida (1994). Disaggregating patents into invention and non-invention patents, we find that the industrial concentration index only leads to significantly higher number of non-invention patent applications but not for invention patent applications. A one unit increase in the industrial concentration index induces a significant 5% increase in non-invention patent applications and an insignificant 3% increase in invention patent applications. The concentration of companies from the same industry may facilitate particularly the diffusion of less advanced knowledge. Such knowledge is probably less strictly concealed by companies within the firm boundary, thus spurring more non-invention patent applications than invention ones.

Companies' engagement in global affairs proxied by the ratio of international trade to GDP (*OPEN*) is not found to be positively associated with innovation success to any extent. In contrast, foreign companies' provincial presence (*FOR*) significantly matters for the provinces' corporate patenting results, especially the non-invention ones. These two variables are usually not considered in the previous studies based on the regional knowledge production function framework. However, our findings that companies' global engagement at the provincial level do not always matter significantly for their patenting results are consistent with our firm-level analysis in Chapter 2. Similar to the explanation above, the finding that foreign companies' presence matters especially for non-invention patenting results may be attributable to a relatively easier diffusion of less advanced and less strictly protected knowledge owned by co-located foreign enterprises to local companies. Moreover, local affiliates of foreign enterprises usually take over the low-tech but labour-intensive part of the overall operations.

Both variables aiming to capture observable regional heterogeneity – size of the province (*POP*) and the share of population (at least six years old) with at least university degree (*HEDU*) – are found to be positively relevant for provincial corporate patenting results. However, only the positive effect of higher education is found to be significant, especially for companies carrying out more sophisticated R&D activities for invention patenting.

Up until now our estimations have looked at contemporary corporate R&D expenditure and companies' province-level patenting activities. There exists a potential endogeneity problem with respect to companies' R&D expenditure, however. To deal with this, we firstly replace the contemporary R&D expenditure with its one- and two-year lags separately in the regression models. Our main results are in line with the findings reported earlier. Companies' R&D expenditure still matters significantly for their patenting activities and this expenditure is especially relevant for invention patents rather than for non-invention patents. In general, companies' average proximity to universities at the provincial level is still found to be significantly relevant for determining companies' patenting results. Proximity only significantly matters for the non-invention patent applications of companies, when total patenting outcomes are disaggregated by patent type. The results for the control variables are slightly different. A higher share of ICT companies in a province, for example, does not lead to a significant increase in invention patent applications, different from our earlier result.[99]

Secondly, we deal with the potential endogeneity of R&D expenditure by applying instrumental variable estimation techniques.[100] We use province-level company size (*SALES*) and companies' capital use relative to their production outputs (*CAPOUT*) in log format and lagged for one year as instruments (see Section 3.3.2.2). Since the estimation results above show that control variables considered also matter for corporate patenting results at the provincial level, we estimated the full models while applying instrumental variable estimation techniques. The relevance of these instrumental variables is supported by the F test results after the first-stage estimation (much higher than 10) and their exogeneity can not be rejected by the overidentification tests (Hansen J Test Statistic) at the usually considered significance levels. The endogeneity tests for the R&D variable (significant at least at the 5% significance level) reveal that we were correct in suspecting endogeneity. These tests underline the substantial importance of applying instrumental variable estimation techniques in the analysis. After estimating the regression models using instrumental variables, Moran's I tests are carried out to investigate whether the error terms are spatially autocorrelated. As the baseline spatial weight matrix, we consider the binary contiguity weight matrix.[101] The null hypothesis that there is no spatial autocorrelation cannot be significantly rejected (at least at the 5% significance level).[102]

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[99] Estimation results are not presented in tables here due to space limitations. They can be obtained upon request.

[100] Here we use the STATA module 'xtivreg2' for analysis (Schaffer, 2010).

[101] The baseline spatial weight matrix considered – with diagonal entries equal to zero – is 'binary contiguity matrix with 1 assigned to neighbour province sharing boundary with the province considered'. We apply two alternative spatial weight matrices: 'inverse exponential distance weight matrix with distance referring to geographic distance between capitals of provinces' and 'inverse exponential distance weight matrix with distance referring to geographic distance between the central points of provinces'. The latter two weight matrices are row-standardised and the distance decay parameter considered in these two matrices equal to 0.05 km^{-1}.

[102] Based on the binary contiguity matrix and the second alternative matrix, the null hypothesis can not be significantly rejected in all cases (at least at the 5% significance level). Based on the first alternative

Table 3.2 shows the estimation results for the three types of patents using instrumental variables in Col. (2), (4) and (6). To help compare the results with the previous estimations, Table 3.2 presents the original findings based on panel OLS in Col. (1), (3) and (5) which are directly extracted from Table 3.1. Results are qualitatively unchanged when we move from the panel OLS to the instrumental variable analysis. However, the magnitudes of the significant coefficients differ slightly. Companies' R&D expenditure is still found to play the most substantial role for determining corporate patenting outcomes. A 1% increase in R&D expenditure induces an even higher increase in patenting results in the case of the instrumental variable analysis (1%) than in the case of the panel OLS (0.8%). The increase in R&D expenditure stimulates more invention patent applications than non-invention ones, similar to the result obtained without the application of the instrumental variables. Regarding the role of academic knowledge in supporting industrial innovation performance, companies' average proximity to universities is found to be, in general, significantly and positively relevant for province-level corporate patenting activities. Again, the instrumental variable analysis also shows that the proximity to universities matters more for non-invention patenting than for technically more demanding invention patenting applications.

Regarding the control variables, a higher share of ICT companies at the provincial level still leads to a significant higher number of patent applications irrespective of patent types. The significant positive effect in the case of the instrumental variable analysis is even slightly higher than was the case in the panel OLS estimation. On the contrary, the effect of industrial concentration on patenting results remains significant as above but the magnitude is smaller. A one unit increase in the industrial concentration index is expected to spur a 3.5% (2.7%) increase in non-invention patent applications (patent applications in general) instead of 5.2% (4.4%). The presence of foreign firms still plays a significant role in this regard. In the case of the instrumental variable analysis, we observe, in particular, an even more pronounced effect for non-invention patenting outcomes. The only qualitative difference between the findings based on the instrumental variable analysis and the significant OLS findings lies in the role of higher education for invention patenting results. While the

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spatial matrix, in which the geographic distance between capitals of provinces is used, the null hypothesis can only be rejected in case of considering all patent applications or all non-invention patent applications as output variables for the year of 2004 (at the 5% significance level).

share of the population (at least six years old) with university degree education was found to be significantly and positively relevant in the panel OLS estimation, the corresponding coefficient becomes insignificant in the instrumental variable estimation.

	P_all		P_inv		P_ninv	
	(1) Baseline	(2) IV	(3) Baseline	(4) IV	(5) Baseline	(6) IV
RD	0.833***	1.007***	0.966***	1.201***	0.819***	0.989***
ACCE	0.008***	0.009***	0.001	0.002	0.006**	0.007**
INDCON	0.044*	0.027*	0.029	0.007	0.052**	0.035*
ICT	0.257**	0.273**	0.278**	0.301**	0.204**	0.220**
HEDU	0.240	0.068	0.487**	0.255	0.106	-0.062
POP	0.901	0.656	1.789	1.459	0.276	0.037
OPEN	-0.099	-0.337	0.073	-0.249	-0.148	-0.381
FOR	0.391*	0.460**	-0.189	-0.096	0.764***	0.831***
IV Tests						
F-Test		83.23***		83.23***		83.23***
Hansen J Test		0.939		1.179		0.083
Endog. Test		5.103**		8.970***		4.876**
Obs.	267	267	267	267	267	267
F	83.28***	88.61***	150.38***	134.67***	75.04***	70.90***
R-sq	0.780	0.773	0.763	0.754	0.703	0.697

Notes: 1. Baseline estimation results from Table 3.1 are presented again in Col. (1), (3), and (5). 2. For Col. (2), (4), (6): fixed effect IV (2SLS) estimation using robust cluster VCE estimator. IV for *RD*: *SALES* and *CAPOUT*. Both IVs are in log format and in one-year lag. 3. All variables except for *ACCE* and *INDCON* are in log in the estimation model. *ACCE* in one-year lag is considered in the regression models. All coefficients are expected to be positive. Hypotheses are tested based on one-tailed tests. ***/**/* refer to 1%/5%/10% significance level.

Table 3.2 – Estimation Results of the Baseline and the Extended Regional Knowledge Production Function by Patent Type (Panel OLS vs. Panel IV-Estimation)

For the following estimation exercises we also apply instrumental variable techniques due to the problem with endogeneity which we earlier diagnosed in relation to the R&D variable.[103] For simplicity, we use the expression ‘regression results’ in the remainder of the paper when referring to results using instrumental variables if nothing else is explicitly mentioned. As the next step, we re-estimate the models using alternative values of the distance decay parameter (γ) to check the robustness of the estimation results with respect to the role of companies’ average proximity to universities for their patenting activities. Table 3.3 presents the corresponding

[103] We run again statistical tests to check the relevance (F-test), the exogeneity of the instrument variables, and the endogeneity of the *RD* variable after estimating the models. In all models estimated, we obtain F-test results much larger than 10 and the exogeneity of the instrumental variables can not be rejected at the usually considered significance levels. The endogeneity test significantly rejects the null hypothesis that the *RD* variable is exogenous in all models except the one considering the quality-adjusted *ACCE* with academic knowledge being embodied in academic journal articles. In the latter case the corresponding p-value is slightly higher than 10%. Test results are reported in Table 3.3 to Table 3.5.

estimation results. The estimation results based on the baseline value of the distance decay parameter (0.05 km^{-1}) are extracted from Table 3.2 and presented again in Col. (2), (5), and (8) to ease the comparison. Col. (1), (4), and (7) show the results using the distance decay parameter set equal to 0.01 km^{-1}, and Col. (3), (6), and (9) those with the distance decay parameter set as high as 0.1 km^{-1}. Explanatory variables, except for the accessibility indicator, which were found to be significantly relevant, remain significant. Moreover, the magnitudes of their effects on corporate patenting hardly change. In contrast, the accessibility indicator which was found to be significantly relevant for corporate (non-invention) patenting (γ = 0.05 km^{-1}), remains significant with a similar magnitude if γ is set equal to 0.1 km^{-1} but it becomes insignificant if γ is set equal to 0.01 km^{-1}.

	P_all			P_inv			P_ninv		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Gamma =	0.01	0.05 (base)	0.1	0.01	0.05 (base)	0.1	0.01	0.05 (base)	0.1
RD	0.954***	1.007***	1.024***	1.153***	1.201***	1.211***	0.957***	0.989***	1.002***
ACCE	0.003	0.009***	0.008***	0.002	0.002	-0.001	0.002	0.007**	0.006***
INDCON	0.029*	0.027*	0.028*	0.006	0.007	0.008	0.037**	0.035*	0.036*
ICT	0.266**	0.273**	0.257**	0.304**	0.301**	0.297**	0.214**	0.220**	0.208**
HEDU	0.035	0.068	0.087	0.216	0.255	0.265	-0.080	-0.062	-0.048
POP	0.636	0.656	0.734	1.346	1.459	1.518	0.045	0.037	0.096
OPEN	-0.316	-0.337	-0.328	-0.251	-0.249	-0.241	-0.364	-0.381	-0.374
FOR	0.487**	0.460**	0.436**	-0.078	-0.096	-0.095	0.849***	0.831***	0.813***
IV Tests									
F-Test	53.85***	83.23***	76.24***	53.85***	83.23***	76.24***	53.85***	83.23***	76.24***
Hansen J Test	1.176	0.939	0.771	1.255	1.179	1.225	0.113	0.083	0.064
Endog. Test	4.786**	5.103**	5.617**	6.253**	8.970***	9.847***	4.473**	4.876**	5.254**
Obs.	267	267	267	267	267	267	267	267	267
F	83.02***	88.61***	100.29***	127.52***	134.67***	123.34***	66.34***	70.90***	92.81***
R-sq	0.777	0.773	0.770	0.759	0.754	0.753	0.698	0.697	0.695

Notes: 1. IV estimation results (with gamma [distance decay parameter] = 0.05 km^{-1}) from Table 3.2 are presented again in Col. (2), (5), and (8). 2. For the other columns: fixed effect IV estimation using robust cluster VCE estimator, considering different gammas. IV for *RD*: *SALES* and *CAPOUT*. Both IVs are in log format and in one-year lag. 3. All variables except for *ACCE* and *INDCON* are in log in the estimation model. *ACCE* in one-year lag is considered in the regression models. All coefficients are expected to be positive. Hypotheses are tested based on one-tailed tests. ***/**/* refer to 1%/5%/10% significance level.

Table 3.3 – Panel IV-Estimation Results of the Extended Regional Knowledge Production Function Considering Different Levels of Distance Decay Parameter by Patent Type

In the latter case with γ set equal to 0.01 km^{-1}, we actually assume that the contribution of universities located about 70 km[104] away from the company to the potential company-relevant academic knowledge is still half of the contribution of universities located in the same city of the company. Based on this assumption, we may overestimate the relevance of universities located far away from the company. This would lead us to assign too high a value for the accessibility indicator to companies in cities where companies there actually have lower accessibility to universities. As a result, the estimation shows that a reduction in the company's distance to universities, i.e., a further increase in one unit in the accessibility indicator does not really support companies in accessing more academic knowledge and producing more (non-invention) patents. In contrast, the similar finding regarding the role of university proximity for corporate patenting in cases with γ equal to 0.05 km^{-1} and 0.1 km^{-1} respectively suggests that only universities located really close to companies, i.e., in the same city are relevant as academic knowledge providers to support companies' (non-invention) patenting activities.

Results so far are based on a strong assumption that universities in China are the same in terms of research quality. The relevance of universities as potential academic knowledge providers for companies is solely determined by the geographical distance, i.e., how easily companies can interact with universities to obtain academic support. In fact, however, universities in China are considerably different from each other with respect to their research quality and capacity. In 2008 there were more than 2,200 universities in China. Only a small portion of these universities were officially selected by two central projects (211-Project and 985-Project) as priority universities and/or universities with the potential for performing internationally competitive research. In total there are currently 112 priority universities and 39 universities with top research capacity in China and more than 30% of these are located in two provincial level municipalities: Beijing and Shanghai (Bickenbach and Liu, 2011a & 2011b). In order to take the different research quality of universities in China into account in our analysis we replace the original accessibility measures by the quality-adjusted ones. Table 3.4 shows the instrumental variable regression results using the first type of quality-adjusted accessibility measure, based on the province ranking by its number of academic invention patent applications. The regression results based on a quality decay parameter

[104] The half-value distance is calculated equal to 'ln(2) divided by the value of the distance decay parameter considered'.

set equal to 0.01 $rank^{-1}$ are presented in Col. (2), (5), and (8), depending on the innovation output variables used. To check for robustness we use a quality decay parameter set equal to 0.005 $rank^{-1}$ and 0.05 $rank^{-1}$, respectively. Their results are presented in Col. (1), (4), and (7), and in Col. (3), (6), and (9). The baseline value of the distance decay parameter (γ = 0.05 km^{-1}) is used for all regression models here.

The regression results are not only consistent across models with different values of the quality decay parameter, but they hardly deviate from the baseline findings estimated without taking university quality into account in our accessibility measures (Table 3.3, Col. (2), (5) and (8)). The findings, as such, do not support our expectation that university quality matters. If university quality plays a role, then the reduction by one kilometre in the distance between companies and the reference university with the best quality is expected to affect corporate patenting activities more strongly than a corresponding reduction in the distance between companies and universities where university quality is not considered. It implies generally higher semi-elasticities with respect to the university accessibility measure. The corresponding coefficients in the case of invention patents are expected to be more likely significant. The findings in Table 3.4 reject our expectation that university quality matters. They suggest that distance plays a more dominant and crucial role than research quality for determining academic knowledge effect on corporate innovation performance in China.

The regression models underlying Table 3.4 are repeated using the same type of quality-adjusted accessibility measures but based on two alternative quality measures for ranking the universities: the number of articles published in academic journals registered in major foreign referencing systems and the amount of university R&D expenditure. No significant difference in regression results can be observed.[105] This may be attributable to the presence of highly significant and positive correlations between the provincial ranking variables based on these three quality variables. Provinces ranked high with a high number of university invention patent applications also rank outstanding with respect to the number of journal articles and to the university R&D investment.

[105] Results can be obtained upon request.

	P_all			P_inv			P_ninv		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Delta =	0.005	0.01 (base)	0.05	0.005	0.01 (base)	0.05	0.005	0.01 (base)	0.05
RD	1.007***	1.007***	1.010***	1.201***	1.200***	1.197***	0.990***	0.990***	0.993***
ACCE_a1	0.009***	0.009***	0.009***	0.002	0.002	0.003	0.007**	0.007**	0.007**
INDCON	0.027*	0.027*	0.028*	0.007	0.007	0.006	0.035*	0.035*	0.035*
ICT	0.273**	0.272**	0.267**	0.301**	0.301**	0.301**	0.220**	0.219**	0.215**
HEDU	0.068	0.067	0.067	0.255	0.254	0.249	-0.062	-0.062	-0.063
POP	0.659	0.663	0.704	1.456	1.453	1.442	0.040	0.042	0.074
OPEN	-0.340	-0.343	-0.366	-0.250	-0.251	-0.264	-0.383	-0.385	-0.403
FOR	0.462**	0.465**	0.486**	-0.095	-0.095	-0.086	0.833***	0.835***	0.851***
IV Tests									
F-Test	83.16***	83.09***	82.15***	83.16***	83.09***	82.15***	83.16***	83.09***	82.15***
Hansen J Test	0.946	0.953	1.000	1.179	1.180	1.195	0.084	0.085	0.092
Endog. Test	5.103**	5.106**	5.219**	8.954***	8.939***	8.889***	4.876**	4.879**	4.962**
Obs.	267	267	267	267	267	267	267	267	267
F	88.70***	88.80***	90.36***	134.95***	135.07***	128.45***	70.76***	70.61***	69.38***
R-sq	0.773	0.773	0.774	0.754	0.754	0.755	0.697	0.697	0.697

Notes: 1. *ACCE_a1* refers to quality-adjusted accessibility measure (Concept 1) and is in one year lag in the estimation models. The base variable used to assess university quality at the provincial level is the total amount of invention patents applied by universities located in the same province. Here quality concept 1 is applied and the base value for delta [quality distance decay parameter] = 0.01 $rank^{-1}$. 2. All columns: fixed effect IV estimation using robust cluster VCE estimator. IV for *RD*: *SALES* and *CAPOUT*. Both IVs are in log format and in one-year lag. 3. All variables except for *ACCE_a1* and *INDCON* are in log in the estimation model. All coefficients are expected to be positive. Hypotheses are tested based on one-tailed tests. ***/**/* refer to 1%/5%/10% significance level.

Table 3.4 – Panel IV-Estimation Results of the Extended Regional Knowledge Production Function Considering Quality-Adjusted ACCE (Concept 1) with Different Levels of Quality Decay Parameter by Patent Type

Different capabilities of universities in producing invention patents and academic papers are expected to exert differing effects on corporate innovation activities, however. Academic invention patents are expected to be closer – in technical terms – to company demand for input technology than academic papers. But the latter may be more easily obtained and at lower cost than the former. Moreover, the relative ability of universities to produce innovation outputs is expected to affect corporate patenting more strongly than university R&D efforts, which are still tied to high risk and uncertainty over future outcomes. In order to consider provincial differences in the relative ability of universities to produce invention patents and academic papers and to engage in R&D investment more explicitly, we apply our second quality concept to calculate the quality-adjusted accessibility measures. Table 3.5 presents the estimation results of the replicated regression models but using the new quality-adjusted accessibility measures. The base value of distance decay parameter (γ = 0.05 km^{-1}) is used for all regression models here and there is no need to consider the quality decay parameter in this quality concept.

	P_all			P_inv			P_ninv		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
QL=	upinv	ujournal	urd	upinv	ujournal	urd	upinv	ujournal	urd
RD	1.026***	0.889***	0.984***	1.204***	1.208***	1.213***	0.996***	0.823***	0.991***
ACCE_a2	4.61e-04***	0.008***	0.004*	1.78e-04	1.75e-05	-3.23e-04	0.001***	0.010***	0.002
INDCON	0.032*	0.030*	0.030*	0.008	0.008	0.008	0.040**	0.036**	0.038*
ICT	0.255**	0.258**	0.256**	0.297**	0.297**	0.297**	0.206*	0.210**	0.207*
HEDU	0.084	0.120	0.083	0.252	0.264	0.266	-0.060	-0.019	-0.041
POP	0.878	0.843	0.796	1.499	1.506	1.515	0.200	0.153	0.173
OPEN	-0.295	-0.293	-0.305	-0.241	-0.242	-0.242	-0.345	-0.343	-0.355
FOR	0.409*	0.386**	0.409*	-0.114	-0.097	-0.093	0.773***	0.739***	0.808**
IV Tests									
F-Test	67.03***	66.48***	98.96***	67.03***	66.48***	98.96***	67.03***	66.48***	98.96***
Hansen J Test	0.441	1.297	0.840	1.020	1.229	1.192	0.011	0.177	0.067
Endog. Test	5.646**	3.681*	5.055**	9.810***	12.104***	8.085***	4.861**	2.676[#]	4.707**
Obs.	267	267	267	267	267	267	267	267	267
F	112.45***	102.49***	88.37***	107.42***	94.84***	94.78***	85.99***	78.41***	91.46***
R-sq	0.769	0.784	0.772	0.754	0.753	0.753	0.696	0.716	0.694

Notes: 1. *ACCE_a2* refers to quality-adjusted accessibility measure (Concept 2) and is in one year lag in the estimation models. 2. Three different base variables are used to assess the university quality: upinv (base), ujournal (academic articles published in journals registered in the major foreign referencing systems) and urd (uni R&D expenditure). 3. All columns: fixed effect IV estimation using robust cluster VCE estimator. IV for *RD*: *SALES* and *CAPOUT*. Both IVs are in log format and in one-year lag. 4. All variables except for *ACCE_a2* and *INDCON* are in log in the estimation model. All coefficients are expected to be positive. Hypotheses are tested based on one-tailed tests. ***/**/* refer to 1%/5%/10% significance level. # The corresponding p-value is 0.102, only slightly higher than 10%.

Table 3.5 – Panel IV-Estimation Results of the Extended Regional Knowledge Production Function Considering Quality-Adjusted ACCE (Concept 2) with Different Measures for University Research Quality by Patent Type

Qualitatively our estimation results are consistent with our baseline findings. Proximity of companies to academic knowledge sources with more invention patents, journal articles and R&D inputs remains significantly and positively relevant for overall corporate patenting activities. In the quantitative terms, we observe some differences in the magnitudes of the proximity effects, depending on the different quality measures used. Specifically, a one unit increase in companies' accessibility to an academic invention patent application induces only a 0.05% increase in corporate patent applications filed. This effect is much smaller than the effect produced by a one unit improvement in companies' proximity to a university (0.9%). More commercially relevant academic knowledge is more easily accessible by a one unit improvement in companies' proximity to a university than the additional amount induced by a one unit increase in companies' accessibility to an academic invention patent. Moreover, the effect of a one unit increase in companies' access to academic invention patents on corporate patenting is additionally smaller than the corresponding effect with respect to academic journals and university R&D expenditure. The latter covariate is only marginally significant for corporate patenting activities in general, however. In fact, it even becomes insignificant for corporate non-invention patents. The finding of relatively low relevance of university R&D expenditure is consistent with our expectation that the highly uncertain outcomes involved in the university R&D processes makes companies unsure about the commercial benefits they could expect to get from interacting with universities.[106]

In addition to university R&D expenditure we recall that academic knowledge is defined here as 1) university production of invention patents and 2) publication of academic journal articles. What is surprising is that the proximity effect of the first measure on corporate patenting is lower than the second effect. One would rather expect that the need for communication and thus the need for overcoming long distance between companies and universities is relatively low for companies to access academic knowledge from academic publications than from university invention patents (e.g. Jaffe, 1989)[107]. On the one hand, university researchers may more comprehensively disclose their findings in journal articles than in patent application documents. On the other hand, journal articles are more easily accessible by companies at low cost. Our finding suggests that other influential factors may impede a free flow of academic knowledge via academic journal articles. For example, such potential factors might be the incomplete disclosure of information in journal articles thereby necessitating firms to get in touch with academics if they are to understand the 'full picture'. In this case, proximity to universities with journal publications helps the transfer of complementary tacit information to companies. In contrast, companies' proximity to academic invention patents does not matter much for their general corporate patenting activities. Such proximity is even found to be not significant for corporate invention patents at all. This may be attributable to the fact that acquiring the licenses to use academic invention patents is relatively costly. This high cost may reduce the willingness of companies to

[106] Most of the previous studies in the US and in Europe proxied academic research with university R&D expenditure. The weak evidence here compared to the stronger findings for Western economies with respect to the role of companies' proximity to academic knowledge proxied by university R&D may be partially attributable to the Chinese government's engagement in expanding university R&D investment which does not yet lead to sufficient amounts of convincing academic findings relevant for industrial needs.

[107] Jaffe noted in his seminal work "If the mechanism is primarily journal publications, then geographic location is probably unimportant in capturing the benefits of spillovers" (Jaffe, 1989: 957).

make use of such academic knowledge for their own innovation activities. Low willingness to access academic knowledge through acquiring university invention patents makes it irrelevant how far away companies are located from universities filing invention patents.

For corporate non-invention patent applications we observe results comparable to those observed for corporate patenting activities in general. A one unit increase in quality-adjusted accessibility of companies to academic journal articles results in a positive effect on corporate non-invention patent applications ten times as high as that induced by a one unit increase in corresponding accessibility to academic invention patents. A further contributing factor, other than those already mentioned, may help explain such difference. The low relevance of companies' proximity to academic knowledge proxied by academic invention patents could be attributable to the per se low relevance of university invention patents with advanced techniques for companies' less sophisticated non-invention patenting outcomes. Again the low relevance of advanced academic knowledge for corporate non-invention patents weakens the role of companies' proximity to universities to obtain that kind of knowledge to support their own innovation activities.

3.5 Conclusion

Profit maximising companies undertake innovation activities to develop new products and/or technologies to enhance their long-term competitiveness. In addition to their own spending on R&D, they draw from external knowledge which has been created by other economic agents. Their own R&D efforts can build on such external knowledge bases, giving further momentum for innovation. Previous literature identified universities to be important knowledge sources for companies (see Section 3.2). However, academic knowledge which has a high relevance for industrial innovation may not be fully disclosed as codified information for external use. Accordingly, face to face communication and interaction to obtain complementary but tacit information may be crucial for companies' success in transforming academic knowledge into commercial use. Hence, proximity of companies to universities may be a key determinant of academic knowledge effects on corporate innovation success.

Silicon Valley and Route 128 in the US are seen as conspicuous cases in point that proximity between companies and universities is advantageous for acquiring tacit knowledge and spurring industrial innovations. The seminal work of Jaffe (1989) has unleashed many econometric studies on the role of academic research on corporate patenting activities. Jaffe (1989) and the subsequent parallel studies focus primarily on the US and, to a lesser extent, on Europe. Comparable research on emerging economies like China is scarce.

This chapter investigated whether firms' proximity to universities and academic knowledge is influential in spurring corporate patenting in China. We documented effects on corporate innovation for the large and medium-sized industrial enterprises which contribute overwhelmingly to innovation in China. The investigation was based on estimating regression models derived from the Griliches-Jaffe regional knowledge production function framework. The investigation used a provincial dataset compiled from various statistical yearbooks in China and consisting of data for 30 provinces in mainland China (2000 to 2008). To measure the proximity of companies to universities, we calculated a corresponding logsum indicator. We first focused on geographic aspects before taking quality differences in university research into account. The logsum accessibility indicator, differing from the indicators used in Jaffe (1989) and Anselin et al. (1997), assumed utility maximising behaviour of firms through accessing academic knowledge.

Our results generally supported the existence of spatial academic knowledge effects on corporate patenting activities in China as found in the previous literature for the US and Europe. However, companies' proximity to universities was only found significantly positively relevant for the technologically less demanding non-invention patents but not for invention patents. Corporate R&D expenditure was found to be the most significant factor for companies filing invention patent applications. Although industrial R&D also matters for corporate non-invention patent applications, the magnitude of the effect here was found to be smaller.

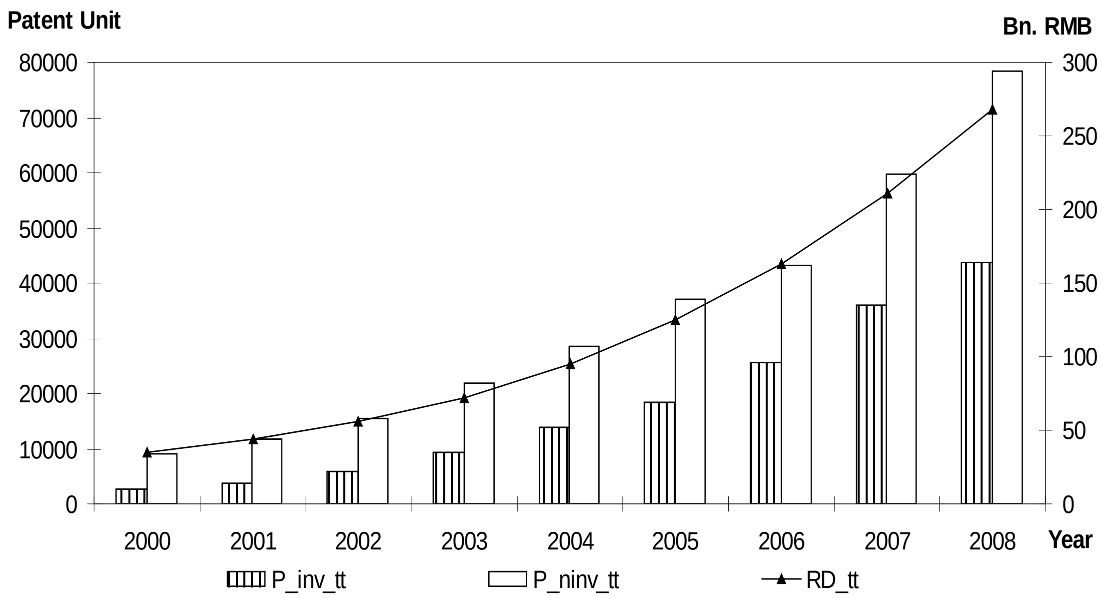
To relax the initial assumption of homogenous university research quality, we used a quality-adjusted accessibility indicator considering provincial rankings according to the university research quality at the province level. However, embodying provincial differences in university research quality did not affect our findings – neither with respect to the magnitude nor the significance of the proximity effect on corporate patenting activities. The results were robust for the application of different values for the quality decay parameter and alternative quality measures for provincial quality ranking. As such, our findings suggested that in contemporaneous China, geographic proximity of companies to universities still dominates over university research quality difference for determining the relevance of universities as knowledge sources for companies.

In order to consider the provincial difference in university research capability and capacity more directly, we applied a second type of quality-adjusted accessibility indicator, where the actual number of academic research outputs and inputs respectively were used instead of the quality ranking measure. Our results showed that companies' proximity to academic knowledge, proxied by different academic research outputs and capacity, affects corporate patenting to varying degrees. Adjusting accessibility by using academic journal articles to proxy the quality of academic knowledge was found to give a much larger effect compared to using university invention patents as proxy. Academic journal articles usually are easily available for readers at relatively low cost. In general, geographic constraints should not play a role for companies to access published academic knowledge as assumed in Jaffe (1989). Our findings may suggest, however, that even in this case, face-to-face communication and interaction between companies and universities are important. Interfacing with publishing academics helps firms to gain the 'complete picture', since in such publications probably not all relevant academic knowledge is fully disclosed nor is fully understandable to readers. The low proximity effect in the case using university invention patents to proxy academic knowledge may indicate that companies may be relatively uninterested in technologically more demanding academic knowledge for corporate non-invention patenting. In the analysis we also used university R&D expenditure as a proxy for academic knowledge. The proximity effect in this case was found to be only marginally significant for overall corporate patenting.

To sum up, the analysis provided some evidence consistent with the existing literature that, in addition to the predominant importance of the companies' own R&D expenditures, universities matter as a knowledge source for corporate innovation performance in China. Companies' proximity to universities plays a relatively more important role than university quality for companies to obtain and profit from academic knowledge for their own innovation activities. Differentiating companies' patenting results by technical requirements and novelty, their proximity to universities seems to play a significantly positive role for accessing academic knowledge efficiently for supporting their non-invention patenting activities only. Future research may pay more attention directly to investigating the relationship between academic research and corporate non-invention patenting in more detail and at a more disaggregated level. It may, for example, try to gain more insights into the technological content and real value of these non-invention (utility model and external design) patents for such an analysis. This may further help explore the potential reasoning why locating closer to universities plays a more crucial role for learning from universities for realising such patents but less crucial for realising the corporate invention patents.

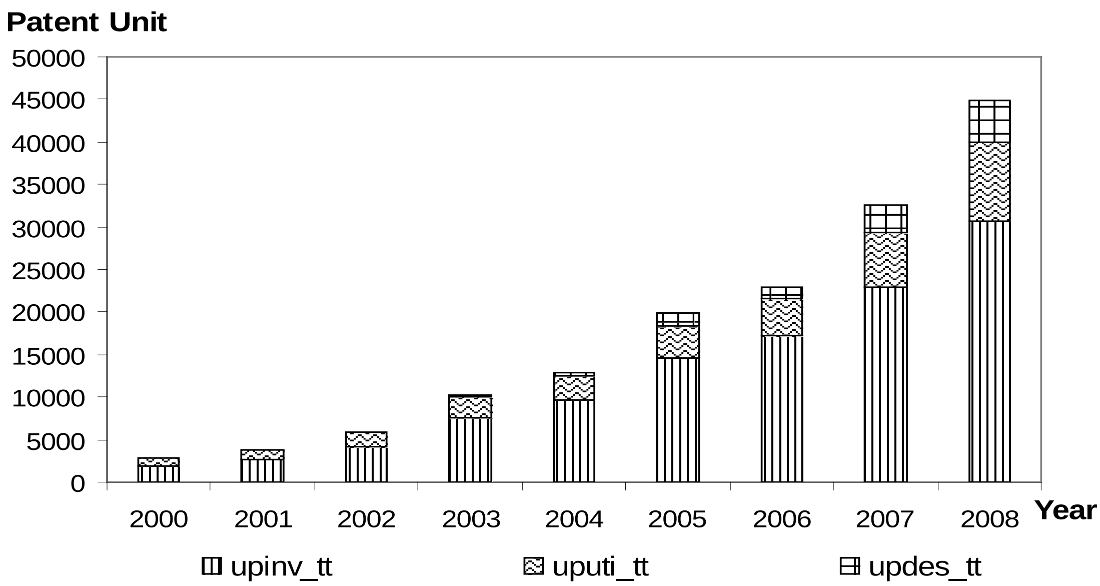
3.A Appendix

Three figures and one additional table are presented here to provide further information related to Chapter 3.



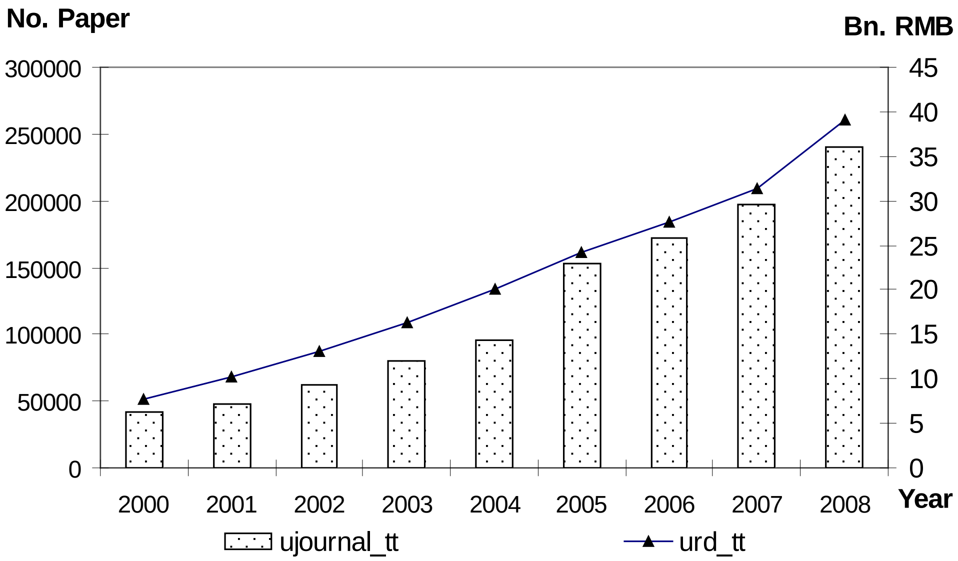
Notes: Sums of the corresponding province-level statistics of 30 provinces in China are presented here. Original data source: NBSC-CNSYST (various years). Own presentation.

Figure 3.A.1 – Total Corporate Patent Applications (Invention vs. Non-Invention) and Industrial R&D Expenditure (2000-2008)



Notes: Sums of the corresponding province-level statistics of 30 provinces in China are presented here. Data source: SIPO-SARP (various years). Own presentation.

Figure 3.A.2 – Total Patents (Invention, Utility Model and External Design) Filed by Universities (2000-2008)



Notes: Sums of the corresponding province-level statistics of 30 provinces in China are presented here. The articles here refer to the Chinese scientific papers taken by major foreign referencing systems such as SCI (Science Citation Index), EI (Engineering Index) and ISTP (Index to Scientific & Technical Proceedings). Data source: NBSC-CNSYST (various years). Own presentation.

Figure 3.A.3 – Total Chinese Scientific Papers Published in the Three Major Foreign Referencing Systems and Universities' R&D Expenditure (2000-2008)

Variable		Mean	Std. Dev.	Min	Max	Obs
lnP_all[1]	overall	6.17	1.59	1.61	10.41	N=300
lnP_all = ln[P_all]	between		1.34	3.02	8.93	n=30
Note: P_all in unit	within		0.89	3.77	7.96	T=10
lnP_inv[1]	overall	5.01	1.64	0.69	9.75	N=270
lnP_inv = ln[P_inv]	between		1.39	1.70	8.23	n=30
Note: P_inv in unit	within		0.90	2.53	6.81	T=9
lnP_ninv[1]	overall	6.94	1.58	1.00	10.68	N=270
lnP_ninv = ln[exp(1)*(1+P_ninv)][7]	between		1.38	3.40	9.60	n=30
Note: P_ninv in unit	within		0.80	4.54	9.15	T=9
lnRD[1]	overall	11.85	1.49	7.21	15.23	N=300
lnRD = ln[RD]	between		1.31	8.40	14.16	n=30
Note: RD in 10,000 RMB	within		0.75	9.76	13.61	T=10
ACCE[2]	overall	36.42	19.45	-31.20	88.61	N=270
Note: 1 year lag, gamma at the base	between		17.97	7.24	85.34	n=30
value	within		8.07	-13.12	62.52	T=9
INDCON[3]	overall	54.35	4.62	45.75	72.81	N=267
Note: INDCON: index * 100	between		4.33	48.36	66.46	n=30
	within		1.75	48.88	60.70	T=8.9
lnICT[3]	overall	1.94	0.55	1.00	3.32	N=267
lnICT = ln[exp(1)*(1+ICT)][7]	between		0.53	1.15	3.16	n=30
Note: ICT: share * 100	within		0.16	1.25	2.96	T=8.9
lnHEDU[46]	overall	1.66	0.55	-0.15	3.41	N=300
lnHEDU = ln[HEDU]	between		0.48	0.94	3.13	n=30
Note: HEDU: share * 100	within		0.28	0.33	2.22	T=10
lnPOP[4]	overall	3.51	0.78	1.63	4.58	N=300
lnPOP = ln[POP]	between		0.79	1.68	4.55	n=30
Note: POP in mio.	within		0.04	3.35	3.65	T=10
lnOPEN[4]	overall	2.88	1.05	1.15	5.19	N=300
lnOPEN = ln[OPEN]	between		1.03	1.63	4.99	n=30
Note: OPEN: ratio * 100	within		0.25	2.07	3.53	T=10
lnFOR[4]	overall	2.18	0.83	0.11	3.80	N=300
lnFOR = ln[FOR]	between		0.83	0.56	3.75	n=30
Note: FOR: share * 100	within		0.17	1.35	2.69	T=10

Notes: [1]Source of data or core data for calculating the variables: NBSC-CNSYST (various years). [2]Source of data or core data for calculating the variables: NBSC-CCSY (various years).[3]Source of data or core data for calculating the variables: Provincial Statistical Yearbooks for all provinces except for Tibet (various years). [4]Source of data or core data for calculating the variables: NBSC-CNSY (various years). [5]Source of data or core data for calculating the variables: SIPO-SARP (various years). [6]Data of *HEDU* in 2001 are average values calculated from the data of *HEDU* in 2000 and 2002, since the base data needed to calculate *HEDU* in 2001 are not available. [7]In case of P_ninv (ICT) two (eight) original observations are zero.

Table 3.A.1 – Key Descriptive Statistics of Variables Considered in the Estimated Regression Models

Variable		Mean	Std. Dev.	Min	Max	Obs
ACCE_a1_upinv[25]	overall	33.65	20.35	-35.59	88.38	N=270
Note: 1 year lag, base values for delta	between		19.00	2.42	85.17	n=30
and gamma	within		7.98	-15.28	59.16	T=9
ACCE_a1__upjournal[12]	overall	33.53	20.36	-36.59	88.58	N=270
Note: 1 year lag, base values for delta	between		18.98	1.62	85.31	n=30
and gamma	within		8.07	-15.89	59.75	T=9
ACCE_a1__urd[12]	overall	33.54	20.38	-36.60	88.58	N=270
Note: 1 year lag, base values for delta	between		19.00	1.66	85.31	n=30
and gamma	within		8.05	-15.88	59.56	T=9
ACCE_a2__upinv[25]	overall	37.57	105.63	-1420.18	164.39	N=270
Note: 1 year lag	between		55.80	-132.03	139.28	n=30
	within		90.20	-1250.58	229.06	T=9
ACCE_a2__ujournal[12]	overall	100.90	40.15	5.72	212.53	N=270
Note: 1 year lag	between		37.73	29.27	199.51	n=30
	within		15.21	33.95	138.76	T=9
ACCE_a2__urd[12]	overall	163.63	35.92	51.03	261.54	N=270
Note: 1 year lag	between		33.20	104.20	249.12	n=30
	within		14.86	89.99	196.42	T=9
lnSALES[1]	overall	16.85	1.18	13.95	19.73	N=270
lnSALES = ln[SALES]	between		1.03	14.64	18.70	n=30
Note: SALES in 10,000 RMB, 1 year lag	within		0.62	15.53	18.39	T=9
lnCAPOUT[1]	overall	4.19	0.51	3.04	5.22	N=270
lnCAPOUT = ln[CAPOUT]	between		0.28	3.60	4.65	n=30
Note: CAPOUT: ratio * 100, 1 year lag	within		0.42	2.76	4.88	T=9

Notes: [1]Source of data or core data for calculating the variables: NBSC-CNSYST (various years). [2]Source of data or core data for calculating the variables: NBSC-CCSY (various years).[3]Source of data or core data for calculating the variables: Provincial Statistical Yearbooks for all provinces except for Tibet (various years). [4]Source of data or core data for calculating the variables: NBSC-CNSY (various years). [5]Source of data or core data for calculating the variables: SIPO-SARP (various years). [6]Data of *HEDU* in 2001 are average values calculated from the data of *HEDU* in 2000 and 2002, since the base data needed to calculate *HEDU* in 2001 are not available. [7]In case of P_ninv (ICT) two (eight) original observations are zero.

Table 3.A.1 (continued) – Key Descriptive Statistics of Variables Considered in the Estimated Regression Models

4 The Impact of Active Innovation Policy on Academia-Industry Linkages

For the working paper version of this chapter see Liu, W.-H. (2009), Academia-Industry Linkages and the Role of Active Innovation Policies – Firm-level Evidence in Hong Kong, Kiel Working Paper 1577, Kiel Institute for the World Economy (http://www.ifw-members.ifw-kiel.de/publications/academia-industry-linkages-and-the-role-of-active-innovation-policies-2013-firm-level-evidence-in-hong-kong-1).

4.1 Introduction

Chapter 3 investigated the role of universities for industrial innovation at the province level in China, taking into consideration the geographic proximity of firms to universities as well as university research quality. The analysis results provided some evidence for the existence of spatial academic research effects on industrial patenting activities. Geographic proximity of firms to universities dominates over university research quality for determining the relevance of universities as potential academic knowledge sources for firms. Despite the positive relevance of firms' proximity to universities for especially their non-invention patenting results, for firms' both invention and non-invention patenting results their own R&D engagement stills play a more substantial role.

Both universities and firms are crucial stakeholders of national innovation systems (NIS). Their activities and interactions create, modify and diffuse new technologies (e.g. Nelson, 2000) and upgrading and innovation is key for sustaining long-term economic growth (NSF, 1972). How efficient and effective their activities and interactions would be depends strongly on the institutional constellation of the NIS, on which governments are expected to have considerable influence.

Research activities of academic institutions such as universities and research institutes aim, in general, to expand the stock of public knowledge, which is beneficial for the society as a whole. But such social benefits are often difficult to be adequately appropriated among innovators. Due to such difficulty, private innovators like firms are less willing to engage in doing research in this area. In contrast, research activities of firms aim to obtain new knowledge, based on which they can develop new technologies or/and new products to increase their profits (Dasgupta and David, 1994). Different research goals and research outcomes between academic institutions and firms make efficient interactions between them essential in order to maximise the social welfare of an economy. To encourage more intensive academia-industry linkages, governments may play important roles. Bozeman (2000) summarises three technology policy paradigms based on different theories – the market failure paradigm, the mission paradigm and the cooperative paradigm – substantiating governments' preferences for more passive or more active roles in implementing technology policies to affect incentives of academic institutions and firms for innovation and interactions. However, empirical evidence on the effects of different government roles in designing and implementing technology policies on the intensity of innovation and interaction between academic institutions and firms is inconclusive.

Hong Kong (HK), due to its specific historical background, is a highly interesting case for empirically investigating the effects of different government roles in implementing technology policies on innovation and interactions between academic institutions and firms. Compared to the other three Asian Newly Industrialised Economies – South Korea, Singapore and Taiwan – innovation intensity in HK measured in R&D expenditure-to-GDP ratio was especially low (Brahmbhatt and Hu, 2007). After the handover of HK to China and the Asian financial crisis in the late 1990s, HK government decided to play a more active role in promoting innovation, especially industrial innovation in HK. Since then, HK government is not just a provider of institutions friendly to industrial upgrading anymore. It has become a potential financier and active supporter of firms' innovation activities. Most notably, it began to more actively promote interactions between firms and academic institutions for innovation. This change in HK government's role in implementing technology policies provides a favourable research base for investigating the effects of alternative government policies on innovation incentives and academia-industry linkages.

Several case studies were carried out to study the effects of HK's post-1997 innovation policies on academia-industry linkages (e.g. Patchell and Eastham, 2001 & 2003; Poon and Chan, 2007; Sharif and Baark, 2008a). Most of these studies investigated the issue of academia-industry linkages from the point of view of universities or/and research institutes. Moreover, they investigated the issue in a more qualitative way based on very few but in-depth interviews with personnel from selected HK universities. In contrast, this chapter tries to fill, to some extent, an empirical research gap left in the existing literature by conducting related research from firms' point of view. Focusing on firms' point of view, it investigates the role of HK government's more active innovation policy for enhancing firms' innovation incentives and their willingness to engage in more intensive interactions with academic institutions. More specifically, this chapter focuses on three such linkages: academic institutions as innovation sources, as innovation partners and as training bases of highly-qualified labour for firms. We base our research on statistical and econometric analyses using both official statistics and an original dataset collected from our own questionnaire survey among HK electronics small- and medium-sized enterprises (SMEs) with operations in the Pearl River Delta (PRD) in 2007.[108]

This chapter is organised as follows. In Section 4.2 we introduce the concept of NIS, the rationales for implementing technology policies and the abovementioned policy paradigms (Bozeman, 2000) to delineate the theoretical framework of our analysis. We also summarise empirical findings from previous studies related to our research topic. In Section 4.3 we describe innovation policy in HK, focusing especially on the innovation policy after 1997. We also briefly introduce the innovation policy in the nearby PRD, where the interviewed HK firms carry out some of their business operations.

In Section 4.4, we describe the analytical methods used and the survey background. More concretely, in order to gain more insights into the potential effects of changing governmental policies for industrial innovation, the analysis is carried out in three steps. Firstly, we analyse the development of innovation activities in HK based on the official statistics starting from 1995 – more than two years before the return of HK to China and its start to transform itself to an active innovation promoter – to 2007. Although the period analysed before the start of active innovation policies in HK is not very long, the consideration of innovation activities in HK in this period in our analysis gives us an opportunity to compare the development of innovation activities before and after the initiation of the active innovation policies in HK. Secondly, focusing on 2007 – ten years after HK's return to China and its start to act as an active innovation promoter – we analyse a unique dataset collected from our own survey which addressed HK electronics SMEs only, in addition to analysing comparable official statistics covering all HK companies. HK innovation policies do not treat all industries equally. The HK government provides more incentives for firms from the selected focus

[108] This survey 'HK Company Survey 2007' aimed at gaining more insights into HK firms' operational practices to find out the potential edges of HK firms over their competitors in global markets. Above all, it focused on investigating how HK firms flexibly and informally react to the global market challenges. This chapter only analyses a subset of survey data collected. The part of survey questionnaire analysed for this chapter is presented in Table 4.A.1 in the appendix (Section 4.A).

industries including the electronics industry than for firms from non-focus industries (Section 4.3). Comparing the innovation activities of HK electronics SMEs based on our dataset with the innovation activities of all HK companies is expected to provide some more information on whether HK innovation policies may more strongly motivate firms from focus industries to innovate than HK firms on average. Thirdly, at an even more disaggregated level we apply econometrics techniques to have an exploratory analysis on whether active innovation policies as implemented in HK may affect innovation activities in terms of academia-industry linkages of firms which indeed perceive the policy changes more strongly than others.

Following the research strategy as described above, we present the results of the three-step research analysis in sequence in Section 4.5. It means, firstly we describe the development of innovation activities in HK over time based on secondary statistics. Secondly, we provide some survey findings on the current innovation activities of HK electronics SMEs and their links to academic institutions. Corresponding official statistics for HK firms in general are provided as well for comparison. Thirdly, we introduce two groups of probit models, based on which some econometric findings on the role of HK government's more active post-1997 innovation policy for HK electronics SMEs' decisions to engage in different academia-industry linkages are provided. Section 4.6 concludes.

4.2 Literature Background

The concept of national innovation systems (NIS) was firstly introduced by Freeman, Lundvall and Nelson (Nelson, 2000). NIS is a "set of institutions that generate and mould economic growth, to the extent that one has a theory of economic growth in which technological innovation is the key driving force" (Nelson, 2000: 11). Within the NIS, institutional players from the public and private sectors interact and determine together the economy-wide innovation performance. Firms, academic institutions including universities and research institutes, and governments are the three main groups of institutional players involved in the NIS. The international study led by Richard R. Nelson found that there is no one-size-fits-all construction of NIS for different countries with different economic and political developing background. However, his research team identified the following common characteristics among different sets of NIS investigated. Firstly, given weak central planning, firms are the principal providers of goods and services and the main technological innovators of NIS.

Secondly, education is mainly conducted in public institutions such as public schools and universities. Thirdly, governments are in general responsible for funding basic research. But the degree to which they actually do fund basic research and which (groups of) institutional players do carry out basic research are found to be different across countries (Nelson, 1993; Nelson and Rosenberg, 1993).

Carrying out basic research requires huge investment of both financial and human capital and results of basic research are normally bounded with high risks and uncertainty. In addition, it is generally difficult for innovators to directly and adequately appropriate the returns to basic research results. This reduces the willingness of firms to devote substantial resources to performing basic research. To enhance firms' incentives to perform basic research, governments may financially support their respective activities. However, the conflict between governments' interests to promote the expansion of public knowledge through increased basic research and firms' interests to keep sensitive research findings secret to maximise their own profits limits the willingness of governments to fund firms to carry out basic research. Instead, governments are probably more willing to financially support academic institutions to carry out basic research. Compared to firms, academic institutions are expected to be more willing to make their findings publically available through teaching and training, journal publications and presentations at conferences etc. (Dasgupta and David, 1994).

Given that firms have full relevant information as assumed in the neoclassical economics, academic basic research findings are expected to be easily and efficiently absorbed and transformed by profit-maximising firms into advanced technologies and innovative products to satisfy customer demand and thereby increase social welfare without additional governments' interventions. However, deficiency in the institutional environment in which firms and academic institutions operate may prevent firms from obtaining full relevant information, which then impedes them to acquire and efficiently transform academic knowledge into commercial use. To enhance the efficiency of markets in the allocation of information and technology, governments may then restrict their roles to removing market barriers and to providing well-established institutions such as "appropriate intellectual property right policies, free trade agreements, neutral impact taxation, and limited regulation of enterprise" (so-called 'market failure technology policy paradigm' in Bozeman, 2000: 632).

However, governments' engagement in improving institutional environment does not guarantee a high transferability and optimal use of academic basic research findings by firms. Even operating in an improved institutional environment "markets are not always the most efficient route to innovation and economic growth" (Bozeman, 2000: 631). Audretsch et al. (2002) argued, for example, that high risks and uncertainties of developing frontier technologies, lacking technological capabilities of individual firms, and remaining appropriation problems in the development of applied technologies may still impede firms from efficiently exploring basic research findings and transforming them into commercial use. Aghion et al. (2009) also argued that different innovators being unaware of potential complementarities between their research and innovation results may hinder them from coordinating their innovation plans efficiently thus preventing the economy from realising optimal innovation results. To cope with such problems, governments may engage in more active innovation policies to directly promote academia-industry linkages as suggested under the 'cooperative technology policy paradigm' (Bozeman, 2000). They may provide more direct financial supports or tax exemptions to increase innovation cooperation incentives of firms with academic institutions. In addition, they may encourage universities and found public research institutes to carry out applied research to provide applied technologies in addition to basic research results to firms for commercial use.[109]

As to the innovation policies implemented by the HK government over the past decades, there was a clear change in the policy paradigms from the 'market failure technology policy paradigm' to the 'cooperative technology policy paradigm'. While the HK government acted as a mere provider of institutions friendly to industrial upgrading before 1997, it has become to play a more active role in promoting industrial innovation and especially academia-industry linkages since 1997.[110]

Focusing on the two policy paradigms relevant for the case of HK, previous empirical studies find some evidence regarding their positive effects on industrial innovation in general and on firms' engagement in academia-industry linkages in particular. Hall et al. (2001) and Revilla Diez and Mildahn (2007), for example, provided some empirical support for the 'market failure technology policy paradigm'. Hall et al. (2001) found that the quality of intellectual property rights and the appropriability of corporate innovation results matter for determining firms' incentives

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[109] The third policy paradigm proposed by Bozeman (2000) is called the 'mission technology paradigm'. Different from the 'market failure technology policy paradigm', here governments also perform R&D on their own but limit themselves to certain clearly-specified missions based on national interests, e.g. national security, energy, and public health etc.

[110] See Section 4.3 for more information on the innovation policy in HK.

for cooperating with academic institutions. Revilla Diez and Mildahn (2007) emphasised the substantial importance of an entrepreneurship-friendly environment for promoting the foundation of spin-off firms. Empirical findings as to the effects of policies following the 'cooperative technology policy paradigm' were less clear. For example, after the initiation of Bayh-Dole Act in the US and the establishment of public R&D labs to promote innovation activities and to encourage interactions between academic institutions and firms in different countries since the late 1970s, a strong increase in the interactions between academic institutions and firms has been identified over time. However, findings on whether such an increase in interactions is indeed attributed to innovation policies were inconclusive.[111] Despite rather inconclusive findings in Western countries, empirical studies for Asia, especially those conducted in Taiwan and South Korea, found that innovation policy implemented by a more active government, encompassing founding research institutes for applied research to support industrial innovation and setting up science parks etc., tends to have a positive effect on firms' innovation activities and their interactions with academic institutions (e.g. Eriksson, 2005).

In contrast to the literature summarised above, studies which investigated the effects of different innovation policies on firms' innovation incentives and their decisions on academia-industry linkages are scarce. Lin et al. (2010) investigated this issue by comparing the effects of different innovation policies in Taiwan and in Ireland. They argued that the stronger innovation performance in Taiwan may be attributed to the more active innovation promotion of the Taiwanese government.

Overall, there are three main academia-industry linkages identified by the literature (Bozeman, 2000; Feldman et al., 2002; D'Este and Patel, 2007). Firstly, firms use academic institutions as their innovation sources to acquire patents and licenses developed by academic institutions, to search for academic consultancy or to acquire academic publications for their own knowledge exploration. Secondly, firms cooperate with academic institutions for innovation. In this case, they financially support academic research or directly undertake joint research projects with academic institutions. Thirdly, firms take academic institutions only as training bases of highly-qualified workers. To enrich their innovation capabilities they directly hire students or graduates and attract researchers from academic institutions to join their research teams.

[111] See Bozeman (2000) for an overview of the related studies.

Different kinds of innovation policies may affect firms' decisions for academia-industry linkages differently. And even the same innovation policies may have different effects on firms' decisions, if they perceive these policies differently. Rubenstein et al. (1977), for example, conducted a survey supported by the US National Science Foundation to investigate firms' perception of government incentives to technological innovation in the UK, France, West Germany and Japan, focusing on firms' awareness of innovation policies and their perception of relevance and potential effects of such policies. They found empirical support for their proposition that different firms from different countries may have different information about and hold different attitudes towards government action relevant to R&D and innovation processes. Given such perception differences, the extent and the ways in which firms adapt their operations to the changing innovation policies may also differ. This further implies that the theoretically expected policy effects on firms' innovation incentives and their engagement in academia-industry linkages may not be observed among firms with different perceptions.

In addition to differences in (perceived) innovation policies, different industry and firm characteristics may also matter for innovators' engagement in academia-industry linkages (Bozeman and Coker, 1992; Bozeman, 2000; Bekkers and Bodas Freitas, 2008). Regarding the role of different industries for firms' decisions on academia-industry linkages, academic institutions as innovation partners were found to be especially important for R&D intensive industries and for industries whose technological development is rapid (Cohen et al., 2002; Schartinger et al., 2002). Moreover, academic institutions as training bases for providing highly-qualified labour for firms' innovation activities were found to be especially important for the electronics industry (Balconi and Laboranti, 2006). In contrast, academic institutions as innovation sources seem to be of similar importance for firms across different industries.

Regarding the role of company characteristics for companies' decisions on different academia-industry linkages, three characteristics were often examined: age, technological capabilities and size (e.g. Bozeman and Wittmer, 2002). With respect to company age, Bozeman and Wittmer (2002) found that younger firms are more likely to cooperate with research institutes to develop new products. Cohen et al. (2002) found, more generally that academic research seems to be more important for start-ups' R&D activities than for incumbent firms, suggesting a generally higher importance across different types of academia-industry linkages for younger firms. With respect to technological capabilities, empirical studies argued that firms are required to have certain technological capabilities to be able to establish efficient and effective academia-industry linkages. This suggested that different types of academia-industry linkages are likely to be more important for firms with higher technological capabilities (Ham and Mowery, 1998; Fontana et al., 2006). As to the role of firm size for firms' decisions about academia-industry linkages empirical findings were less clear. Bekkers and Bodas Freitas (2008) suggested that large firms with abundant resources are more likely to cooperate with academic institutions or to financially support academic research than small firms. They argued that small firms may, instead, prefer to rely on academic institutions as training bases that provide sufficient highly-qualified labour for their innovation activities. In contrast, Santoro and Chakrabarti (2002) found that small firms may rely more strongly on innovation cooperation with academic institutions to gain access to the costly but highly-qualified research capacities and facilities in such institutions. They also found that large firms may have higher incentives to work on joint education programs with academic institutions.

4.3 Innovation Policies in HK and in the PRD

As indicated in Section 4.1, this chapter attempts to gain more insights into the role of more active innovation policy for intensifying firms' innovation incentives and for increasing firms' willingness to interact more intensively with academic institutions for innovation, using HK with its specific historical background as an example. Before doing the corresponding statistical and econometric analysis, we, thus, delineate at first the main features of the innovation policy in HK in this section. Since a great part of HK firms operate in the neighbouring PRD region, we also briefly introduce the innovation policy in the PRD.

Before 1997, "because of HK's economic success in competing primarily on the basis of cost, innovation was not seen historically to be important by the actors in HK innovation system, including most notably the colonial government" (Sharif, 2006: 508). Thus, it is often argued that there was effectively no industrial and innovation policy in HK at that time (Kwong, 1997). The HK (colonial) government's adherence to market principles was translated into its laissez-faire attitude and non-interventionist industrial policies. In line with the 'market failure technology policy paradigm' of Bozeman (2000), the government confined its role to that of a provider of business-friendly institutions and infrastructures that helped firms in HK to exploit market opportunities according to their own interests (Tuan and Ng, 1995). In addition, it emphasised the importance of a healthy development of the higher-education sector for providing an increasing amount of highly-qualified labour for HK firms to sustain HK's long-term economic growth. In the beginning of the 1990s, the government, thus, granted university status to two local polytechnics and two colleges. Universities were the most important innovators within the NIS in HK at that time (Sharif, 2006).

To promote a healthier and more balanced economic development, after the Asian financial crisis in 1997, the Commission on Innovation and Technology (CIT) was set up to clarify the role of innovation for HK's future and to identify which measures the HK government should undertake to encourage innovation activities (HKSAR, 1998; Baark and Sharif, 2006). Following recommendations from two CIT reports[112], the HK government has continuously increased its direct involvement in promoting industrial and economic development in HK and has gradually changed its role from being a mere institution provider to being an active innovation promoter since then. It has placed a special focus on promoting academia-industry linkages for innovation consistent with the 'cooperative technology policy paradigm' of Bozeman (2000). It added the University-Industry Collaboration Programme (UICP) into the newly founded Innovation and Technology Fund (ITF) with an initial injection of 5 billion HKD in 1999.[113] Private companies registered in HK applying for funding under the UICP are asked to search in advance for adequate local universities in HK as innovation cooperation partner (ITC, 2002).[114] In 2000, the Innovation and Technology Commission (ITC) was set up to "spearhead HK's drive to become a world-class and knowledge-based economy". The ITC "formulates, develops, and implements government's policies … to promote innovation and technology". Above all, it devotes itself to "promoting and supporting applied R&D, and technology transfer and

[112] After producing the two reports in 1998 and 1999, the CIT was immediately disbanded (Sharif, 2006).

[113] HKD means Hong Kong Dollar. Since 1983 the exchange rate (HKD/USD) has been fixed at 7.8 (HKCSD, 2008). USD is an abbreviation for US Dollar. There was 'Industry Support Fund (ISF)' established in 1994 to support the industrial and technological development in HK. However, the initial injection of ISF was significantly smaller than that of ITF. While initiating the ITF, the ISF was subsumed to be one of the programs of ITF.

[114]In HK there are 13 degree-awarding higher education institutions, including eight institutions funded by the University Grants Committee (Chinese University of HK, City University of HK, HK Baptist University, HK Institute of Education, HK Polytechnic University, HK University of Science and Technology, Lingnan University, University of HK), four self-funded institutions (Chu Hai College of Higher Education, Hang Seng Management College, HK Shue Yan University and Open University of HK) and the publicly-funded HK Academy of Performing Arts (See http://www.edb.gov.hk/ for more information.).

application" (quotations from the ITC official website[115]).[116] In the same year, the Hong Kong Applied Science and Technology Research Institute (ASTRI) was established. ASTRI is assigned to conduct applied R&D based on the research results of the universities and to transfer its own and universities' findings to firms. ASTRI should act as a bridge to facilitate knowledge flows between universities and firms.[117]

The HK government intends to increase indigenous innovation activities so that the strong reliance of HK firms on high-tech machines and technologies imported from external suppliers may be gradually reduced.[118] To do so, the ITC announced the 'new strategy' in 2005 as the second wave of innovation promotion, which consisted of two key initiatives. The first key initiative was to identify technology focus areas where innovation should be especially heavily promoted. In doing so the following criteria were considered: (i) existing research capabilities of academic institutions, (ii) HK firms' competitive advantages, (iii) industrial needs and (iv) market potentials. In total, nine focus areas were identified.[119] The second key initiative was to set up R&D centres to facilitate the information and technology transfer between universities and companies (ITC, 2005). Till 2006, six R&D centres were founded. Because ASTRI's research is strongly related to the four electronics-related focus areas (see Footnote 119), the R&D centre of information and communications technologies is subsumed under ASTRI. In addition, the new strategy introduced a new three-tier funding structure for the ITF. Under this three-tier funding structure, R&D centres are taken as the first-tier receivers of funding.[120] In other words, HK firms searching for governmental financial support for innovation are encouraged to seek more intensive cooperation relationships with these R&D centres (ITC, 2005).

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[115] See http://www.itc.gov.hk/en/welcome.htm for more information.
[116] The functions of the previous HK Industry Department related to innovation and technology have been subsumed to ITC since its establishment (Sharif, 2006).
[117] The Industrial Technology Research Institute in Taiwan, the Korean Advanced Institute of Science and Technology and thirteen industry-specific research institutes and centres in Singapore were used as reference models for the construction of the ASTRI (e.g. HKSAR, 1998).
[118] We obtained this information through background interview with the former Commissioner Wong of the ITC in September in 2007.
[119] Four of them are related to the electronics industry: communications technologies, consumer electronics, integrated circuit design, and opto-electronics. The other five identified focus areas are automotive parts and accessory systems, Chinese medicine, logistics/ supply chain management enabling technologies, nanotechnology and advanced materials, and textile and clothing.
[120] Individual innovation projects belonging to the other areas identified in the ITC's consultation paper (ITC, 2004) but were not chosen as one of the nine focus areas under the 'new strategy' would be promoted by the ITF as the second-tier receivers. The third-tier receivers cover the projects whose innovation outcomes cannot be used commercially immediately.

As many HK firms have some operations in the neighbouring PRD in the Chinese province Guangdong, innovation policy in the PRD may also affect their incentives to innovate and to engage in academia-industry linkages. The Guangdong government determined the innovation policy in the PRD, following the innovation-related decisions made by the Chinese central government.[121] In 2005 when the national and provincial construction of the 11th five-year plan was in progress and when the ITC in HK announced its 'new strategy', the Guangdong government announced its 'Decision on Enhancing Indigenous Innovation Capability and Improving Industry Competitiveness' (hereafter: Decision). This Decision called for establishing an institutional environment conducive to indigenous innovation and it clearly specified that firms should be the major technological innovators and should receive increasing support from academic institutions (GDGOV, 2005). However, the inherent shortage of highly-qualified labour and research-intensive academic institutions in Guangdong may limit the quality and scope of support potentially provided by the academic institutions on site. Against this background, to more effectively promote academia-industry linkages in Guangdong, firms in Guangdong have been encouraged to search for academic support for their innovation activities from the academic institutions in nearby HK. They have also been encouraged to found new enterprises in HK to apply for financial supports from the ITF for their innovation activities (GDSTC, 2004). More comprehensively, the Decision in 2005 called for strengthening regional and international innovation cooperation. It called for cooperating with HK and Macao to establish regional innovation centres for international technological cooperation and public platforms for industrial design. In this regard, it focused especially on further developing core technologies for the main supportive and strategic industries of the region and it aimed at building in the long run a valuable regional brand 'co-designed by Guangdong, HK and Macao and produced in the PRD' (GDGOV, 2005).

In summary, innovation policies in both HK and Guangdong promote industrial innovation and encourage explicitly academia-industry linkages. For HK firms having some operations in the PRD both policies are relevant. However, due to HK's comparative advantages in providing highly-qualified labour and research-intensive

[121] The four main innovation-related decisions of the Chinese central government in the past decades are the 'Decision on the Reform of the Science and Technology System' in 1985, the 'Decision on Accelerating Scientific and Technological Progress' in 1995, the 'Decision on Strengthening Technological Innovation and Developing High Technology and Realising its Industrialisation' in 1999 and the 'Decision on Implementing the Medium-and Long-term Strategic Plan for the Development of Science and Technology and Improving the Indigenous Innovation Capability' in 2006 (OECD, 2008).

academic institutions and HK firms' strong connection to their home market, innovation policy and institutions in HK are expected to be of greater importance for HK firms' decisions on academia-industry linkages.

4.4 Research Method and Survey Background

Making use of HK's policy experience, this paper attempts to gain some more insights into the potential effects of more active innovation policy on firms' innovation incentives and their willingness to engage in different academia-industry linkages to fill the gap of the empirical literature. To do so, a three-step research strategy is applied. Firstly, we analyse the development of innovation activities in HK based on the available official statistics starting from 1995 to 2007. Although the period analysed before the start of active innovation policy in HK is not long, the consideration of innovation activities in HK in this period in our analysis gives us an opportunity to compare the development of innovation activities before and after the initiation of the active innovation policy in HK. Secondly, focusing on the last year of the research period (2007), we analyse our own survey data of HK electronics SMEs in addition to corresponding official statistics covering all HK companies. Because the more active innovation policy in HK since 1997 does not treat firms from all industries equally and the electronics industry was selected as one of the focus industries, comparing the innovation activities of HK electronics SMEs based on our dataset with the innovation activities of all HK companies is expected to provide some more information on whether HK innovation policies may more strongly motivate firms from focus industries to innovate than HK firms on average. The dataset analysed here was collected by our own HK Company Survey 2007[122] which addressed HK electronics SMEs with operations in the PRD to gain additional, more detailed, insights into HK electronics SMEs' innovation incentives and their engagement in different academia-industry linkages.[123] Assumed that the more active innovation policy following the 'cooperative technology policy paradigm' of Bozeman (2000) may indeed have potential to affect economy-wide innovation activities in a positive way, it does not mean that shortly after the implementation of such policies, all HK electronics SMEs on

[122] A subset of the questionnaire including the questions used for the analysis in this paper is presented in Table 4.A.1 in the appendix (Section 4.A). The full questionnaire can be obtained from the author upon request.

[123] The questions were designed, following the definitions of OECD (2005) and the question examples from the previous Community Innovation Surveys which were regularly conducted in Europe.

site will intensify their engagement in all kinds of academia-industry linkages for supporting their innovation activities. Instead, as introduced in Section 4.2, how they perceive the changes of the policies and recognise the preferential treatments they may obtain by following the policy suggestions is expected to matter. Thus, as the third step, we estimate two groups of probit models to investigate the potential relationships between the active innovation policies perceived by the HK electronics SMEs and their willingness to engage in different academia-industry linkages, controlling for other potential influential factors suggested by the literature (see Section 4.2). In this way we attempt to learn more about whether HK active innovation policy may affect innovation activities in terms of academia-industry linkages of firms which indeed perceive the policy changes more strongly than others.

Regarding academia-industry linkages, here we focus on the following three linkages: academic institutions as innovation partners, innovation sources, and training bases of highly-qualified labour for firms. These three types of linkages differ from each other in the degree of direct involvement of firms in related activities. We suppose that firms are most directly and actively involved when they have academic institutions as their innovation partners, less so when academic institutions serve as innovation sources and even less when they serve as training bases of highly qualified workers.

As mentioned above, we addressed the HK Company Survey 2007 to HK electronics SMEs. We focused on SMEs instead of large companies, because of the prevalence of SMEs among all the firms registered in HK (98%, HKSCC, 2008). We focused on the SMEs from one single industry to reduce the potential industry heterogeneity problem, enabling a more clear investigation of the policy-innovation relationships of interest. We selected the electronics industry as our focus industry due to the following reasons. Firstly, the electronics industry is one of the focus areas being selected and promoted by the innovation policy in HK.[124] Comparing our survey results with available official statistics related to the innovation activities of all HK firms may support us to gain more information about potential policy effect on innovation activities of focused firms relative to HK firms on average. Secondly, although the literature presented above suggested that academic institutions as innovation sources are important for companies across industries, academic institutions as innovation partners

[124] If we did not choose the electronics industry but certain industries that were not explicitly promoted by the innovation policies, it would be impossible to learn more about the potentially realised direct effects of changing policies on the innovation activities of companies from those industries.

are found to be more important for firms from R&D intensive industries or/and from industries with highly dynamic technological development. The electronics industry, whose products encompass, for example, different kinds of information and telecommunication technological products with different functions and sophistications, is obviously one of the industries characterised by high R&D intensity and a highly dynamic technological development. Thirdly, academic institutions as training bases of highly qualified labour force were even found to be especially important for electronics firms directly (see Section 4.2). Given the fact that HK SMEs in general lacked willingness to carry out innovation till late 1990s (e.g. Chiu and Wong, 2001; Sharif, 2006) and may just start to innovate currently, we may thus obtain first more clear evidence for our research aim, if we focus on HK electronics SMEs which are expected to be more willing to engage in different academia-industry linkages.[125] The focus on the electronics industry may fourthly be justified by its high importance for the HK's economy and especially for its foreign trade (HKCSD, 2007a). Electronics products accounted for about 50% of HK's foreign trade including imports and exports in 2006. Although only about 5% of all manufacturing firms in HK were electronics firms in 2005, they realised about 10% of whole value added of the HK manufacturing sector in the same year. However, the share of value added of the HK manufacturing sector realised by the electronics industry was very likely underestimated, if HK electronic firms' production activities in the PRD were not taken into account properly. HK electronics firms were among the first movers which relocated their production activities into the PRD since the open-door policy in the late 1970s (e.g. Berger and Lester, 1997; Enright et al., 2005). Over time, the PRD became the main production base of many HK electronics companies. In 2006, the gross output value of the electronics industry amounted to 41% of all industries above a designated size in Guangdong as a whole (GPBS, 2007).[126]

[125] SMEs from other industries for which academia-industry linkages are not expected to be especially important for innovation may not engage in such linkages when they just start to redesign their business strategies towards more innovation in the future. In this case, it would be more difficult to identify relationships between their perception of changing innovation policies and their engagement in academia-industry linkages, even when there are indeed such relationships. In this case, such relationships may be better identified at later time points.

[126] The gross output value of industry above a designated size consists of the output value of 'all state-owned enterprises' and that of 'non-state-owned enterprises with annual business revenue of over 5 million RMB'. In 2006, the gross output value of industry above a designated size accounted for about 87% of the gross output value of industry with all enterprises in Guangdong (GPBS, 2007).

We obtained basic information on the electronics SMEs for our survey from the company data bank of the HK Trade Development Council (TDC)[127], in which 4,572 HK firms were registered as electronics SMEs operating in the PRD in September in 2007. Our local cooperation partner, Social Sciences Research Centre (SSRC) at the University of Hong Kong, sent interview invitations to 3,000 firms randomly selected from the TDC data bank. In total, senior executives of 104 firms agreed to give personal interviews to complete the questionnaires.[128] Additionally, the SSRC carried out follow-up work by phone to clarify unclear responses. We were aware that this survey method would be time- and cost-consuming for the executives interviewed, but it was considered essential to ensure a high quality of data obtained.[129]

Constrained by the availability of data from the TDC data bank, the representativeness of the interviewed firms for the HK electronics SMEs as a whole is examined by the criterion of firm size only. Firm size is measured by the number of employees. All 104 interviewed firms were asked to indicate the number of their employees in HK at the end of 2006. To comply with the public definition of the SMEs in HK, we exclude two firms with more than 100 employees in HK.[130] So we end up with 102 effective firm samples. These 102 interviewed firms and the SMEs in the original TDC databank with information on their firm size can be grouped into six

[127] The TDC is a statutory body established in 1966 by ordinance. It offers a wide range of services to facilitate the creation of opportunities in international trade for the HK-based firms, especially HK SMEs. URL: http://www.hktdc.com/.

[128] Before starting the survey, one-day training was provided by the author in June, 2007 to the SSRC researchers who joined the project. Through the training, the SSRC researchers were informed about the following points: research goal of the HK Company Survey 2007, reasoning and focus of every question in the questionnaire, ways to identify executives' misunderstandings based on the linkages between questions and responding alternatives in complicated cases. After the training, pilot tests were carried out by contacting 23 electronics firms suggested by the TDC as the firms with the highest potential for interviews in short time. In total, interviews with senior executives from 3 of these 23 electronics companies were carried out during the three-week pilot test period. Results of pilot tests and feedbacks from the SSRC researchers were taken into consideration to revise the questionnaire. A survey manual for the SSRC researchers was then provided based on the revised questionnaire to inform them about all the changes.

[129] Each personal interview took on average 60 minutes. The content of the interviews was based on the standardised survey questionnaire. The survey included not only innovation-related questions which may have less misunderstanding problems if we sent the questionnaire to the CEOs by post but also questions related to the overall business orientation of the firms and their attitudes towards using informal institutions such as personal relationships for doing business in HK and in the PRD etc. which were expected to have a large potential not being correctly understood by the executives, given no other personal explanation. Thus, we decided to go through the whole questionnaire with the senior executives by personal interviews instead of conducting post surveys in order to ensure a higher quality of the data obtained.

[130] See HKSCC (2008) for HK's definition of SMEs.

categories according to their firm size measured in the number of employees.[131] Table 4.1 presents the share of companies by staff range in HK for the sample and for the whole population. The two-sample Kolmogorov-Smirnov test for equality of distribution functions shows no significant difference between the distribution of the 102 companies interviewed and that of the whole population ($p = 0.575$). This suggests the sample is representative for the whole population of HK electronics SMEs in the GPRD at least based on their firm size distribution.

Staff number	≤ 5	6-10	11-15	16-25	26-50	51-100	Total
102-company	52	27	6	8	4	3	100
Population	44	28	9	9	7	3	100

Source: TDC dataset and own HK Company Survey 2007.

Table 4.1 – Company Distribution by Staff Size in HK in %
(102-Company Sample and Whole Population)

4.5 Results

Following the 3-step research methods introduced in Section 4.4, we present the research results in this section as follows. In Section 4.5.1 we present analytical results of selected official statistics on innovation activities in HK over the past decades covering both periods before and after the HK government changed its attitude from a mere institution provider to a more active innovation promoter. In Section 4.5.2 we present survey results on HK electronics SMEs' innovation incentives and their engagement in different academia-industry linkages in 2007 – ten years after the start of the policy change towards innovation promotion in 1997. Corresponding statistics of HK firms in general are provided for comparison. In Section 4.5.3 we introduce our estimation models and present the estimation results as to the effects of changing innovation policies perceived by firms on their engagement in academia-industry linkages.

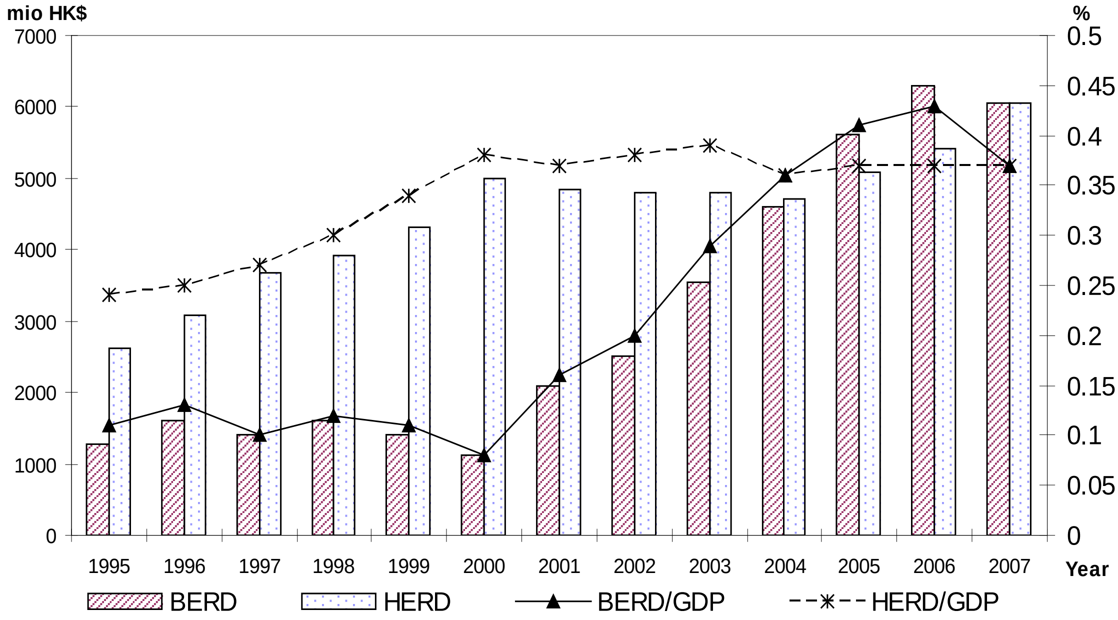
4.5.1 General Trends of Innovation Activities in HK

HK gross domestic expenditure on R&D (GERD) in 1995 – two years before HK's return to China and its initiation of more active innovation policy was only as high as 4 billion HKD, which was roughly 0.38% of HK's GDP in the same year. Over the period

[131] The exclusion rate of our sample – 2 of 104 (1.9%) – is consistent with that in the population of all registered electronics SMEs, where the staff range of 91 of 4,572 companies (2%) is beyond the upper bound of the SME definition in HK and 29 of the 4481 electronics companies registered in TDC data bank do not indicate the staff range in HK. Thus, the representativeness check is based on the firm population of 4452 firms in total.

from 1995 to 2007 HK's GERD continuously increased from the low level in 1995 to 5.6 billion HKD in 1998 and further to 12.4 billion HKD in 2007, which was more than tripled compared to the 4 billion HK as GERD in 1995. The continuous and strong increase in GERD resulted in an increase in the GERD-to-GDP ratio from 0.38% in 1995 to 0.43% in 1998 and further to 0.77% in 2007 (Sharif and Baark, 2008b; HKCSD, 2009a). The continuous increase in GERD and the corresponding share over time in general and the much stronger increase in both variables in the period from 1998 to 2007 in particular reflects a continuous increase in innovation engagement in HK as well as a more substantial growth in innovation intensity of HK in the period after 1997. This overall increase was accompanied by a shift in the relative size of public and private research expenditures. Figure 4.1 shows R&D expenditures in million HKD and as a ratio of GDP of the two main innovators in HK – universities and firms. In 2007 universities and firms invested each about 0.37% of the HK GDP in their R&D activities, compared to 0.24% (universities) and 0.11% (firms) in 1995. The development of this ratio by universities and firms also show that firms have increased their innovation intensity almost continuously since 2000[132], while universities have kept their innovation intensity relatively stable over the same period. As a result, the innovation intensity of firms exceeded that of universities for the first time in 2005.

[132] Despite their increasing R&D investment over time, it is worth noting that, as found by Huang and Sharif (2009), HK (manufacturing) firms still seem to engage in R&D activities less intensively than the domestic manufacturing firms in the nearby Guangdong province. The increase in industrial productivity in Guangdong was found to be strongly attributed to the increasing R&D investment of domestic manufacturing firms instead of to the productivity spillover of HK (Macao and Taiwan) firms through their capital investment on site.

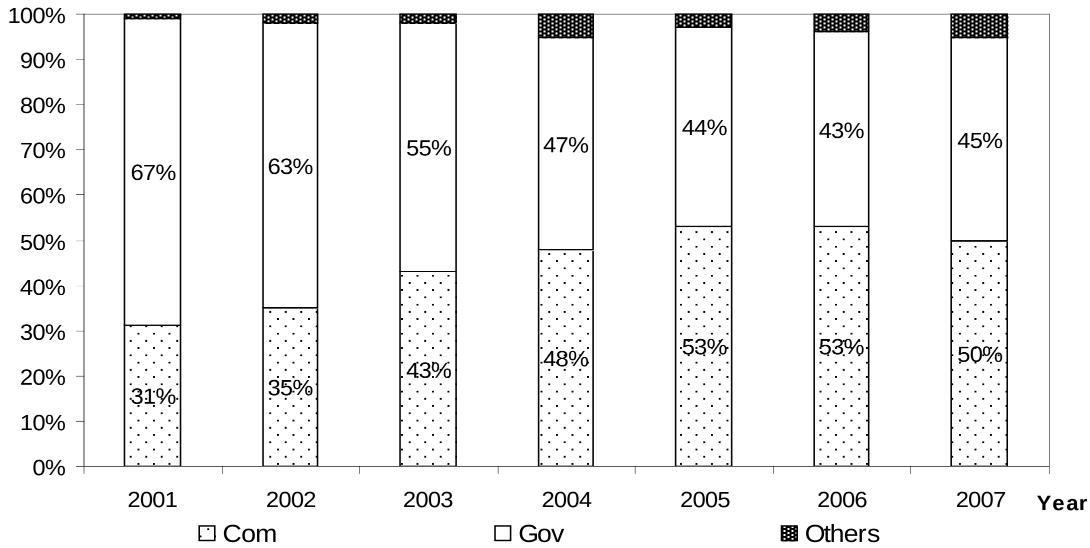


Notes: BERD refers to Business Expenditure on R&D and HERD refers to Higher Education (University) Expenditure on R&D. Own presentation based on data from HKCSD (2007b & 2009a).

Figure 4.1 – Expenditure of R&D Performed by Companies and Universities in HK (1995-2007)

Research funds of the HK universities are mainly provided by the HK government. In addition, the HK government also financially supports public R&D institutes to carry out applied research to facilitate the transfer and commercialisation of academic knowledge. The R&D expenditure of governmental bureaus/departments and R&D centres as a ratio to the GDP amounted to 0.02% annually since 2002, compared to 0.01% from 1995 to 2001 (Sharif and Baark, 2008b; HKCSD, 2009a).

These findings seem to support our expectation that active innovation policy may have a positive effect on the economy-wide innovation incentives in general and on industrial innovation incentives in particular. However, this does not mean that in case of active innovation policy most of the R&D expenditure, irrespective of R&D performers, will be financed by the government. Instead, effective active innovation policy towards more industrial engagement in innovation should be able to enhance firms' incentives to invest own capital in their R&D activities. Figure 4.2 shows the distribution of R&D expenditure by sourcing sectors since the new century in HK and gives some support for this expectation. In 2001, less than five years after the start of active innovation promotion in 1997, still about 67% of GERD in HK was financed by the HK government. This was more than twice the share of GERD financed by HK firms. However, over the last years, the share of GERD financed by the HK government decreased almost continuously, while that financed by HK firms increased. As a result, the share of GERD financed by firms exceeded that financed by the HK government for the first time in 2005. In 2007, 50% of the GERD was financed by HK firms and 45% by the HK government.



Note: 'Com' means companies and 'Gov' means government. Own presentation based on data from HKCSD (2007d & 2009b).

Figure 4.2 – Gross Expenditure on R&D in HK by Sourcing Sector (2001-2007)

During the past decade when the active innovation policies have been implemented in HK, HK firms did not just increase their own R&D investment and strengthen their in-house R&D engagement. Instead, HK firms seem to increasingly recognise the importance to cooperate with academic institutions and to also benefit from their innovation capabilities. According to HKCSD (2007c), in 2007 about 17.8% (17.1%) of HK firms engaging in technological innovation cooperation cooperated with universities (or public technology support organisations such as ASTRI and other R&D centres), compared to 9.7% (1.2%) in 2005.[133] Most of these cooperative academic institutions including universities and R&D centres were located in HK. Similar figures are also observed when specifically focusing on the (smaller) group of firms carrying out cooperative R&D activities.

[133] In 2005, the HKCSD considered for the first time the 'public technology support organisations' separately from other governmental bureaus/departments in their 'Report on Annual Survey of Innovation Activities in the Business Sector'. Thus, we could not compare the figures in 2007 with those from other years earlier than 2005.

4.5.2 Innovation and Academia-Industry Linkages of HK Electronics SMEs

Statistical data suggest that with the implementation of more active innovation policy HK innovators especially HK firms have increasingly strengthened both their own innovation investment and their engagement with academic institutions for carrying out innovation activities. In this section, we analyse our own survey data collected in 2007 on the innovation activities of HK electronics SMEs and their relationships with academic institutions. As mentioned in Section 4.4, 104 HK electronics SMEs completed the survey questionnaires. However, two of them do not satisfy the official SME definition in HK (HKSCC, 2008). These two companies are not included in the following analysis.

As explained above, the focus of the study on HK electronics SMEs is substantiated by our expectations that HK electronics SMEs may be more willing to innovate than before on the one hand and than other HK companies on the other hand. Thus we investigate first the innovation incentives of the HK electronics SMEs to examine whether some support can be found for our expectations. After that, we investigate firms' engagement in different academia-industry linkages.

Innovation incentives

The survey addressed the issue of the HK electronics SMEs' innovation incentives by asking the senior executives interviewed to evaluate the importance of 'increasing innovation activities' as a strategy of their company, using a five-level Likert scale with '1' indicating very important and '5' not important. About 72% of 102 the executives interviewed evaluated 'increasing innovation activities' as a very important or important strategy for their company. In the same question, executives were also asked to evaluate the importance of a strategy of cost reduction for their company – a strategy which was claimed to be the core strategy for sustaining HK firms' competitiveness over decades (e.g. Sharif, 2006). The share of executives evaluating 'cost reduction' as a very important or important strategy is similar to that for the innovation strategy. More generally, the hypothesis of the same distribution of importance levels (across companies) for the two strategies cannot be rejected ($p = 0.362$), suggesting a similar importance of innovation and cost reduction for the HK electronics SMEs.[134] Taking earlier studies which found that HK firms had a much higher preference for cost

[134] Based on Wilcoxon Signed Rank Test (WSRT).

reduction than for innovation into account (e.g. Chiu and Wong, 2001; Sharif, 2006; Sharif and Baark, 2008b), this finding implies that HK electronics SMEs may have increased their willingness to innovate in recent years.

To better sketch the innovation activities undertaken by the HK electronics SMEs, non-innovative firms were filtered out by a survey question which asked firms to indicate whether they carry out innovation activities or not.[135] 88 of 102 executives (86.3%) responded that their company carries out innovation activities. The share of innovative firms in our sample is much larger than that of all HK firms in 2007 (42.2%) based on the official statistics (HKCSD, 2007c). This suggests that HK electronics SMEs are, as expected, more willing to innovate than HK firms in general.[136] Although one cannot argue directly, based on the two findings – HK electronics SMEs become more willing to engage in innovation activities in 2007 than before and they are more willing to do so than HK firms in general – that it is the policy change which has motivated HK electronics SMEs to innovate more intensively, these two findings are still at least consistent with our expectation of expected positive effects which policy change of HK governments towards active innovation promotion may have.

Academic institutions as innovation sources

Given the importance HK electronics SMEs attribute to innovation and the strong emphasis of the innovation policies in HK and in the PRD on promoting academia-industry linkages, we expect that HK electronics SMEs may be more active than other HK firms in interacting with other innovators in general and with academic institutions in particular. We therefore investigate HK electronics SMEs' engagement in the three different academia-industry linkages (academic institutions as innovation sources,

[135] As mentioned above, innovation definition from the OSLO Manual (OECD, 2005) was applied in our study.

[136] One may expect that this finding can be driven by a kind of sample bias that the most innovative firms are more willing to be interviewed. On the one hand, the survey was called 'HK Company Survey 2007' and it did not focus on firms' innovation activities only. We neutrally formulated our motives why we would like to invite companies to participate in this survey, namely we would like to know more about HK firms' operational practices to find out the potential edges of HK firms over their competitors in global markets. Innovative firms were not especially incentivised to respond to the interview invitation. On the other hand, the representativeness test based on the firm distribution by size cannot reject the hypothesis of indifference in the firm distribution of the interviewed firms and the distribution of the whole firm sample from the TDC databank. Since firm size is one of the major determinants of innovation capability of firms (e.g. Kamien and Schwartz, 1975), the indifference in firm distribution gives some support for our assumption that different innovation capability of firms should not be a major determinant of the responding preference of firms.

innovation partners, training bases of highly qualified workers for HK electronics SMEs) by analysing different survey questions.

Focusing first on HK electronics SMEs' innovation sources, executives from the 88 innovative firms were asked to assess the importance of eight alternative sources in total from which their company obtains innovation-related technologies and information.[137] These alternatives can be roughly separated into two groups: internal and external sources. Internal sources consist of own R&D department (OwnRDD), own production-related department (OwnPDD), own marketing-related department (OwnMKD) and the hiring of highly-qualified workers (HQWorkers). Externally, companies can obtain innovation-related knowledge and technologies from academic institutions (Academia), other companies or individuals (OtherCom) or by directly acquiring innovation products from other innovators (DirectAcq). As presented in Table 4.2, all four internal sources were assessed by more than 50% of the executives from the 88 innovative electronics SMEs as being very important or important innovation sources for their company. The shares of executives evaluating own R&D department and own marketing department as very important or important sources even amounted to about 70%. In contrast, academic institutions as innovation sources seem to be the least important for the HK electronics SMEs. Only 15% of the 88 responding executives evaluated academic institutions[138] as very important or important sources for their company and about 35% evaluated them as not important at all.

Results of two-tailed pairwise WSRTs also suggest a strictly lower importance of academic institutions as innovation sources as compared to all other sources considered (at a significance level of 1% for each case). Nevertheless, it is worth noting that the company share regarding academic institutions as important innovation sources in the survey is still much larger than the share from the official statistics based on all HK innovative firms. According to the official statistics, only about 0.95% of HK

[137] The last sourcing alternative is 'others'. Only five firms ever used other sources. Thus, this source alternative is not further considered in the analysis.

[138] Academic institutions mentioned in this question and in the question regarding innovation partners (see below) were literally not restricted to the academic institutions in HK and in the PRD. However, given empirical findings in Chapter 3 and in related literature (e.g. Jaffe, 1989; Anselin et al., 1997) that proximity matters for the effect of academic knowledge on industrial innovation, we assumed that when HK companies consider to source from or cooperate with academic institutions, they may tend to consider academic institutions in HK or in the PRD instead of those located far away. In addition, as mentioned in Section 4.3, HK companies may consider academic institutions in HK rather than those in the PRD due to the higher quality and intensity of academic research in HK. HKCSD (2007c) also gives some statistical support for HK companies' higher preference for cooperating with academic institutions located in HK than elsewhere.

innovative firms assessed universities as highly important sources for their technological innovation, while the corresponding share assessing research institutes as highly important sources was even significantly smaller. At least 98% of HK innovative firms even did not make use of such institutions at all for their technological innovation in 2006 (HKCSD, 2007c). This suggests that HK electronics SMEs are more willing to source innovation-related knowledge from academic institutions than HK companies in general as expected above, although HK electronics SMEs still consider other innovation sources, especially the internal ones to be more important than academic institutions.

	OwnRDD	OwnPDD	OwnMKD	HQWorkers	Academia	OtherCom	DirectAcq
1	40	17	30	24	5	13	11
2	30	34	39	34	10	33	19
3	15	23	19	25	28	35	36
4	2	11	1	7	22	7	9
5	14	15	11	10	35	13	24

Notes:[a] A 5-level importance scale was applied: 1 – very important, 2 – important, 3 – of normal importance, 4 – of little importance, 5 – not important. Source: Own HK Company Survey 2007.

Table 4.2 – Company Share by Importance[a] of Different Innovation Sources in % (n=88)

Academic institutions as innovation partners

In addition to simply absorbing research results from academic institutions, firms may actively cooperate with academic institutions for innovation to benefit from their expertise. Indicators presented in Section 4.5.1 show that an increasing share of HK innovative firms which cooperate with external innovators has engaged in technological innovation cooperation with academic institutions over time. In our case, a similar or even a higher share of HK electronics SMEs is expected to cooperate with academic institutions.

Different from the official statistics, we decided to focus on HK electronics SMEs which indeed (also) innovate in the PRD. Such decision was substantiated by the consideration that a great part of HK electronics SMEs relocated their manufacturing activities to the PRD over the past decades and efficient technological innovation in electronics industry may require HK electronics SMEs to innovate near their production facility to enable efficient interactions and communication between production and innovation activities. In total, 70 of 88 HK innovative electronics SMEs (79.5%)

innovate in the PRD and 51 of these 70 HK electronics SMEs cooperate[139] with other innovators to carry out their innovation activities. About 67% (53%) of these 51 firms cooperate with their customers (suppliers) for their innovation projects,[140] while only 10% of them have academic institutions as innovation partners. Contrary to our expectation, this share (10%) is smaller than the share of HK firms carrying out cooperative technological innovation with universities (17.8%, see Section 4.5.1) and public technology support organisations such as ASTRI and other R&D centres (17.1%, see Section 4.5.1). Such difference can not be attributed to the fact that in our survey we considered not only technological innovation (product and process innovation) but also non-technological innovation (organisational and market innovation), for which academic institutions may play less important roles as innovation partners, because executives from more than 90% of the HK electronics SMEs carrying out cooperative innovation in the PRD indicated that their company carries out technological innovation. However, the lower share of HK electronics SMEs cooperating with academic institutions for innovation does not necessarily mean that academic institutions as innovation partners are less relevant for the HK innovative electronics SMEs than for the HK firms with technological innovation as a whole. Instead, as mentioned in Section 4.5.1 most of the academic institutions with which HK firms choose to cooperate for technological innovation are located in HK. Only 4.4% (1.1%) of these companies cooperate with universities (public technology support organisations such as research institutes) in the PRD (HKCSD, 2007c). Thus, the smaller share of cooperation with academic institutions in our sample may rather be attributed to some other factors such as distance-induced communication problems specific to the electronics industry which may hinder HK electronics SMEs innovating in the PRD from cooperating with academic institutions in HK, although these institutions are characterised with high research quality and intensity.

Academic institutions as training bases

Results above seem to suggest a relatively lower importance of academic institutions, including universities and research institutes, as innovation sources or partners,

[139] The difference between innovation source and innovation cooperation with partners was made clear to firms interviewed by especially emphasising the role of mutual interest and trust and the long-term characteristics for the innovation cooperation.

[140] This result of a high relevance of customers or suppliers as innovation partners for HK electronics SMEs is consistent with results from other surveys (e.g. FHKI, 2003 & 2007).

compared to other potential innovation sources or partners, for the HK electronics SMEs. This may imply that the existence of academic institutions is probably not a substantial criterion for HK electronics SMEs when deciding on concrete innovation locations, unless some other functions of the academic institutions such as training and education plays an important role for them. To gain more information in this regard, we analyse a survey question regarding the criteria considered by firms to decide their innovation location in the PRD. This question asked executives from the companies innovating in the PRD to assess the importance of eight criteria in total, with '1' indicating very important and '5' not important: 'availability of highly-qualified workers and researchers (AvaiHQ)', 'innovation structure, e.g. universities, science parks and venture capital companies etc. (InnoSTR)', 'proximity to companies from the same or related industries (Proximity)', 'tax exemptions and other governmental preferential treatments (PrefTRM)', 'fewer governmental interventions (FGovINT)', 'established legal system (EstabLS)', 'personal or family ties (PersTIE)' and 'others'. As it is possible that SMEs do not make separate decisions on innovation locations but innovate directly close to their production plants, the 70 HK electronics SMEs with innovation in the PRD are classified into two groups: innovating at the production locations in the PRD (dependent locational decision, 59 companies) and innovating at a different location than production in the PRD (independent locational decision, 11 companies). The results on the assessment of the different locational criteria for the two firm groups and for the set of all 70 firms are presented in Table 4.3.[141] Results show that the availability of highly-qualified workers or researchers is taken as very important or important by the greatest share of the responding companies in all three groups. Among firms with independent locational decisions, the corresponding company share is more than 91%, while it is only 46% among firms with dependent locational decisions. In addition, the following criteria – innovation structure, proximity to companies from the same or related industries, and well-established legal systems – are also considered more important by firms making independent location decisions as compared to firms with dependent locational decisions.

As to the importance of existing innovation structures for location decisions, no company with independent location decisions considers this criterion as being very important, 64% of them consider it as important, relative to 9% (very important) and

[141] Only nine of 70 companies specified that there was another important locational criterion for deciding their innovation locations ('others'). Thus, we do not consider it additionally in the following analysis.

12% (important) in the case of dependent location decisions. Although innovation structures include not only academic institutions but also science parks and venture capital companies etc. in the PRD in the survey, the relatively high importance of innovation structures in case of independent location may still be considered as an indication of a high relevance of the existence of academic institutions for firms' independent decisions on innovation locations.

Taking the finding on the substantial importance of the availability of highly-qualified workers for deciding innovation locations and the relatively low research intensity of academic institutions in the PRD into account, a high relevance of academic institutions for decisions on innovation locations in the PRD seems to suggest that some other functions of academic institutions such as teaching and training but not directly their research results, probably matter more for HK electronics SMEs' innovation activities.

	Inno≠Pro n=11	Inno=Pro n=59	Total n=70		Inno≠Pro n=11	Inno=Pro n=59	Total n=70
AvaiHQ				InnoSTR			
1	36	22	24	1	0	9	7
2	55	24	29	2	64	12	20
3	9	29	26	3	19	25	24
4	0	14	11	4	9	22	20
5	0	12	10	5	9	32	29
Proximity				PrefTRM			
1	9	12	11	1	0	9	7
2	46	29	31	2	9	12	11
3	27	29	29	3	36	17	20
4	0	10	9	4	36	25	27
5	18	20	20	5	18	37	34
FGovINT				EstabLS			
1	0	17	14	1	27	12	14
2	27	17	19	2	9	10	10
3	46	27	30	3	27	25	26
4	27	19	20	4	27	27	27
5	0	20	17	5	9	25	23
PersTIE							
1	0	3	3				
2	0	7	6				
3	36	20	23				
4	27	14	16				
5	36	56	53				

Note: The same scale of importance was applied (see Table 4.2). Source: Own HK Company Survey 2007.

Table 4.3 – Importance of Criteria Considered for Deciding Innovation Location (Share of Total Firms in the Corresponding Group, %)

In summary, previous literature argued that academic institutions as innovation sources are important for companies across industries, academic institutions as innovation partners are found to be more important for firms from R&D intensive industries or/and from industries with highly dynamic technological development like the electronics industry (see Section 4.2). Moreover, the electronics industry has been selected as one of the focus industries supported by the HK active innovation policy encouraging intensive academia-industry linkages. However, analysing our survey results and comparing them with available official statistics does not always provide positive support for our expectation that HK electronics SMEs are more willing in engaging in academia-industry linkages than HK firms on average. Our simple comparison only shows that HK electronics SMEs seem to be more willing to source knowledge from universities and research institutes than HK firms on average, although for HK electronics SMEs such academic institutions are not (yet) very important knowledge sources at all. As concerns having academic institutions as innovation partners, HK electronics SMEs are not found to be more willing to do so than their average counterparts. Instead, HK electronics SMEs seem to still appreciate the existence of academic institutions as a crucial criterion for their location decision probably due to their roles as training base of highly qualified workers for the industry. The last finding is also consistent with Balconi and Laboranti (2006) that academic institutions as training bases of highly qualified labour force are especially important for electronics firms.

4.5.3 Role of Active Innovation Policy

4.5.3.1 Estimation Issues

Although innovation policies in HK explicitly promote academia-industry linkages, the analysis above finds that compared to other potential innovation sources and innovation partners academic institutions, including universities and research institutes, are of only low importance for the HK electronics SMEs. However, compared to HK innovative firms as a whole, a larger share of HK innovative electronics SMEs sources innovation-related technologies and knowledge from academic institutions. In this section, two groups of probit models with four different specifications are estimated to better clarify whether there may be some support for the existence of a positive relationship between HK electronics SMEs' perception of changing innovation policies towards more active promotion and their engagement in sourcing from and partnering with academic institutions.

The two groups of probit estimation models[142] have the same model structure:

$$\Pr(Y_i = 1 \mid X_i) = \Phi(X_i'\beta) \qquad (4.1)$$

where Y_i – the dependent variable – refers to whether academic institutions are of at least little importance as innovation sources for a particular firm *i* or not (*source*$_i$, *with 1 for yes and 0 for no*) in the first group, and indicates whether a firm has academic institutions as innovation partners or not (*partner*$_i$, *with 1 for yes and 0 for no*) in the second group.[143] X_i is a vector of explanatory variables of firm *i* and β is a vector of parameters reflecting the effects of *X* on the respective probability.[144] Φ(.) denotes cumulative distribution function of the standard normal distribution. The probit models are estimated with robust standard errors.[145]

For both groups of probit models, four different model specifications are considered. The first two specifications differ from each other only with respect to the set of explanatory variables considered. As mentioned in Section 4.2, the empirical evidence for our research focus, namely effects of changing innovation policies (perceived by firms) on their engagement in academia-industry linkages, is relatively limited compared to the abundant empirical evidence on the industry effects and the effects of firm characteristics on academia-industry linkages of an economy in general. Thus, in the first model specification only factors which have usually been investigated in the literature are considered to be explanatory variables. Different from the other studies, in this study these variables serve only as control variables. In addition, this study focuses on HK SMEs from the electronics industry only; thus eliminating or at least strongly reducing heterogeneity in industry characteristics. In the first model specification of both groups of probit models only firm characteristics usually found to matter in this regard are therefore considered as control variables (see Section 4.2): firm size measured in number of total employees in 2006 in log (*size*$_i$), age measured in difference between 2007 and the starting year of business in HK (*age*$_i$), and innovation

[142] See Greene (2003) p665-666 for more information.
[143] These two variables are codified based on company responses to the two corresponding questions analysed in Section 4.5.2.
[144] Because probit models are non-linear models, estimated coefficients (β) are not equal to the marginal effects of the explanatory variables but they principally provide sufficient information on the directions of the effects of *X* on the outcome probability.
[145] See STATA (2005b) p468-482 and STATA (2005c) p493-496 for more information.

capability measured as the share of sales realised in the ODM (Original Design Manufacturing) and OBM (Original Brand Manufacturing) mode ($capability_i$).

In the second model specification, following our research aim to gain more insights into potential effects of changing policies towards active innovation promotion perceived by firms on their engagement in different academia-industry linkages, we add two policy-related variables as focus variables in addition to the three control variables into the set of explanatory variables. The first policy-related variable refers to firms' attitude towards innovation policies. The more positive firms' attitude towards innovation policies, the greater the effort they can be expected to make to recognise the relevant part of changing policies and to manage their innovation activities and academia-industry linkages to profit from these policies. Because firms were not directly asked to assess the importance of innovation policies for their decisions on academia-industry linkages, a policy proxy is used. This policy proxy is derived from a survey question asking firms to assess the importance of tax exemptions and other local governmental preferential treatments for firms' decisions on innovation locations ($policy_i$). This proxy is reclassified into two dummy variables for the estimation models due to its ordinal characteristics: $policy\_md_i$ and $policy\_st_i$. The former (latter) variable takes value '1' if the corresponding firm assessed governmental policies as little or normally important (important or very important) for its decision on innovation location. Firms with $policy\_md_i$ ($policy\_st_i$) equal to '1' are supposed to have a moderately (strongly) positive attitude towards governmental policies. The second policy-related variable refers to firms' predictability of policy changes in the past five years, with '1' indicating that policy changes are predictable or very predictable ($predict\_dm_i$). The higher firms' ability to predict the changing policies in HK which turn to more actively promote industrial innovation and academia-industry linkages, the more time they can invest to re-design their business strategies and to manage their innovation activities and their academia-industry linkages to profit from the policy changes.

The third and fourth model specifications are used to cope with two potential selection bias problems in our survey. Each of these two specifications includes a binary selection model corresponding to the selection bias considered, in addition to the outcome probit model introduced above as in the second model specification. These two models (selection model and outcome probit model) are jointly estimated by using a full information maximum likelihood estimation method.[146] A potential 'self-selection bias' is considered first. Although focusing on one single industry mitigates to some extent the industrial heterogeneity, electronics firms dealing with different products may differ in the (perceived) sensitivity of business information and thus in their willingness to respond to our interview invitation.[147] To take this self-selection bias into consideration, a new binary variable called '$responding_j$' is created, with value '1' indicating firms' participation in our survey. The subscript *j* refers to j^{th} SME in the TDC data bank.[148] As explanatory variables for firms' responses to our interview invitation, seven different product types are considered: laboratory and scientific equipments ($labequip_j$), audio-visual products ($avprod_j$), computer and peripherals ($pcperi_j$), electrical appliances ($elecappli_j$), telecom products ($teleprod_j$), electronic/electrical components and accessories ($eleccompo_j$) and cameras and photographic equipments ($photoequip_j$). All of these variables are dummy variables with '1' indicating that the corresponding firm deals with certain product type considered.

Secondly, a potential 'sample selection bias' which is determined by a survey question which classified firms interviewed into innovative or non-innovative firms is

146 More concretely, we apply the Stata module 'heckprob' to estimate the third and fourth model specifications, where the two selection models are taken into account. The module 'heckprob' fits the maximum-likelihood probit models with sample selection. See STATA (2005a) p468-475 for more information.

147 One may expect that firms' willingness to respond to our interview invitation can be determined by firms' innovation capability as well in addition to the (perceived) sensitivity of business information argued here. It is worth being noted, however, that the representativeness test based on the firm distribution by size cannot reject the hypothesis of indifference in the firm distribution of the interviewed firms and the distribution of the whole firm sample from the TDC databank. Since firm size is one of the major determinants of innovation capability of firms (e.g. Kamien and Schwartz, 1975), the indifference in firm distributions gives some support for our assumption that different innovation capability of firms should not be a major determinant of the responding preference of firms. Despites, one may also expect that it is possible that firms' different willingness in responding to interview invitations is determined by their prior experiences with academic institutions if they think from the beginning that the survey aims to clarify the academia-industry linkages. However, we expect that such self-selection bias is less relevant for this study due to our neutral survey design. This survey was called 'HK Company Survey 2007' and we neutrally formulated our motives why we would like to invite companies to participate in this survey, namely we would like to know more about HK firms' operational practices to find out the potential edges of HK firms over their competitors in global markets. We did not mention directly that we would study their relationships with academic institutions for innovation.

148 As mentioned in Section 4.4, SSRC sent the survey questionnaires to 3000 firms which were randomly selected from the TDC data bank. We are aware that to consider the first type of potential selection bias problem, information of the 3000 firms should be used. However, the selection of companies was carried out by our local cooperation partner; thus, the list of 3000 selected companies was not available to us. But for all that, because these 3000 firms were randomly selected from the TDC data bank, we decided to use the information of all HK electronics SME in the data bank to enable the estimation of the corresponding selection model. Moreover, taking HK's definition of SME into consideration (HKSCC, 2008), not all 4572 companies but only 4481 companies in the TDC data bank are SMEs. Thus, the subscript *j* may have a maximal value of 4481. The subscript *i* is equal to *j* for the SMEs interviewed in the survey.

considered.[149] In the survey, innovative firms refer to firms which introduce new or significantly improved products into markets or/and implement new or significantly improved processes, organisational modes and market strategies (OECD, 2005). In other words, both firms which did not make any innovation efforts and firms which made efforts but do not yet produce innovative outcomes would be identified as non-innovative firms in the survey. Based on our survey design, only innovative firms were asked to answer questions which provide information for the two outcome variables regarding academia-industry linkages, however. It is thus possible that firms classified as 'non-innovative firms' actually do engage in academia-industry linkages but information about these linkages was not collected.

To cope with this potential sample selection bias, a binary variable called '$inno_i$' is used in the selection model, with value '1' indicating innovative firms and '0' non-innovative firms. Firm characteristics which are available among all interviewed companies and are generally considered in the relevant literature to affect companies inclination to carry out innovation are used as explanatory variables in the second selection model (e.g. Acs and Audretsch, 1990; Aghion et al., 2005; Scott, 2009). In total, three innovation determinants are considered: firm size measured in number of total employees in log ($size_i$, as in the outcome models above), a dummy variable referring firms to be manufacturers or not ($manuf_i$, available from the TDC data bank), and the competition intensity faced by firms ($compet_i$). The last variable is further classified into two dummy variables: facing moderately (strongly) increasing competition pressure or not ($compet\_md_i$ & $compet\_st_i$). Descriptions of the variables used in the estimation models and some basic descriptive statistics for the variables are summarised in Table 4.A.2 in Section 4.A in the appendix.[150]

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[149] Although we do not think that there is a severe responding bias problem determined by firms' difference in innovativeness (see Footnote 136, and Footnote 147), our survey question which differentiates HK electronics SMEs into innovative firms and non-innovative firms based on the Oslo Manual (OECD, 2005) may result in a another kind of sample selection problem, namely that the econometric analysis we have focuses on firms with innovation success only while firms engaging in innovation activities but without success yet are excluded from the analysis. Such sample bias is different from the responding bias among firms and we try to deal with this issue with our fourth estimation model.

[150] Pairwise Spearman correlation coefficients between the independent variables in the full outcome probit model (second model construction) are presented in Table 4.A.3 in Section 4.A. Most of the coefficients are not significant, except for the coefficient between two per se related dummy variables and the coefficient between *size* and *policy_md*. The magnitude of the latter one is however smaller than 0.3 (absolute term). Some of the correlation coefficients of the independent variables in the first selection model are significant (not shown). However, the magnitudes of the significant coefficients are again quite small in general. Correlation coefficients of the independent variables in the second selection model are also not significant except for the one between the two per se related dummy variables (not shown). Thus, we expect that multicollinearity should not be a great problem for our estimations.

4.5.3.2 Estimation Results

Estimation results are presented in Table 4.4 below. The first four columns present results of the four model specifications for the case of academic institutions as innovation sources and the last four columns for the case of academic institutions as innovation partners.[151] As probit models are non-linear models, the estimated coefficients differ from the marginal effects of the explanatory variables. Based on the last model specification in both groups, Table 4.5 reports marginal effects measured at a fixed reference point.[152]

In total, four major findings are worth being discussed in detail. First, the null hypothesis that all regression coefficients are equal to zero cannot always be rejected across the different model specifications.[153] However, for both groups of the probit models (*source* and *partner*), such a null hypothesis can be rejected, based on the last model specification with the second selection model, which dealt with the sample selection bias caused by the innovation classification of firms in the study. Moreover, the correlation between the error term in the outcome model and the error term in this selection model is found to be significantly different from zero in both groups, which suggests that the sample selection bias caused by classifying firms into innovative and non-innovative firms and by only considering innovative firms' relationships with academic institutions is significant. The existence of this type of selection bias makes it necessary and more appropriate to consider the second selection model in this study in addition to the corresponding outcome model. In contrast, the first selection model

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[151] For robustness check, we tried different policy-related variables as proxy variables (e.g. how important are governmental preferential treatments as locational criterion for firms while choosing their production location). Using alternative policy-related variables as such helps cope with potential causality problems between the two outcome variables and policy-related variables used in Table 4.4, because in general cases HK firms made decisions on production locations in the PRD much earlier than their decision on starting to innovate. In addition, size information were added (staff range in HK and staff range in China; partially available from the TDC data bank) into the first selection model. Excluding cases in which no results come out due to convergence problem resulted by data limitation, basic findings as presented in Table 4.4 are hardly affected.

[152] To fix the reference point for measuring the corresponding marginal effects, dummy variables in the outcome models are set to be zero, the other independent variables are set to be at their mean levels. To check the robustness of marginal effects, marginal effects are also measured at different points with different combination of independent variables. In case of setting all dummy variables including those in selection models equal to zero and other independent variables at their mean levels, the magnitude of marginal effects remains as those shown in Table 4.5. In case of setting only complementary dummy variables equal to zero and other variables at their mean levels, marginal effects w.r.t. academic institutions as innovation sources remain as those presented, while marginal effect of the variable (policy_st) w.r.t. academic institutions as innovation partners becomes even larger.

[153] It is worth noting that the limited sample size may make it difficult to establish the best-specified model for our study. Thus, the estimation exercises here are rather to be taken as first econometric attempts to analytically clarify the relationships between HK active innovation policy and firms' decisions on engaging in academia-industry linkages.

(responding or not) does not seem to be relevant as the corresponding error correlations in both groups are not found to be significantly different from zero, which suggests that the potential self-selection bias problem is not significantly relevant in our study.

Second, despite the different specification qualities of the different model specifications, the first policy-related variable (*policy*) is found to matter for firms' decisions to engage in academia-industry linkages. For the case regarding academic institutions as innovation sources, both corresponding dummy variables are found to be significantly and positively relevant. Such positive relationships suggest that the more important governmental preferential treatments for firms' decisions regarding innovation locations in the PRD, the higher the possibility that academic institutions as innovation sources are at least of little importance for companies. Table 4.5 shows that when a reference firm turns to have a moderately (strongly) positive attitude towards governmental policies, the probability that academic institutions as innovation sources are at least of little importance for firms is expected to increase from 35.5% to 59.3% (61.4%).

Such positive relationships are found to be weaker in the case of academic institutions as innovation partners.[154] In this case, only whether firms turn to have a strongly positive attitude towards governmental policies matters. According to Table 4.5, when a reference firm turns to have a strongly positive attitude towards governmental policies, the probability of having academic institutions as innovation partners is expected to be increased from 2.7% to 8.4%. Such positive relationships are consistent with our expectation in the last subsection that the more positive the attitudes of HK electronics SMEs towards governmental policies, the more efforts companies make to manage their resources to engage in academia-industry linkages to benefit from the changing innovation policies on site.

[154] Only the second dummy variable representing a strongly positive attitude of companies towards governmental policies is found to be marginally significant in the second and fourth model specifications.

	Source				Partner			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Policy_md		0.736**	0.628*	0.640***		-0.328	-0.132	-0.285
		(0.364)	(0.421)	(0.239)		(0.563)	(0.429)	(0.548)
Policy_st		0.826**	0.687*	0.697***		0.926*	0.529	0.908*
		(0.463)	(0.529)	(0.281)		(0.620)	(0.527)	(0.597)
Predict_dm		0.388	0.295	0.301**		0.599	0.109	0.545
		(0.401)	(0.400)	(0.129)		(0.523)	(0.418)	(0.491)
Size	-0.047	-0.022	-0.026	0.015	0.055	0.033	-0.030	0.033
	(0.083)	(0.096)	(0.085)	(0.063)	(0.148)	(0.147)	(0.143)	(0.145)
Age	0.020	0.016	0.012	0.007	-0.022	-0.026	-0.013	-0.025
	(0.017)	(0.019)	(0.018)	(0.013)	(0.028)	(0.026)	(0.021)	(0.024)
Capability	-0.001	0.003	0.002	0.003	-0.001	-0.001	0.002	-0.001
	(0.004)	(0.005)	(0.004)	(0.004)	(0.005)	(0.007)	(0.006)	(0.006)
_Cons	0.369	-0.364	-1.515	-0.616	-1.411***	-1.561***	-2.946***	-1.689***
	(0.414)	(0.588)	(1.732)	(0.474)	(0.494)	(0.541)	(0.362)	(0.505)
Selec. model 1 (Responding):								
Labequip			0.191				0.222	
			(0.438)				(0.428)	
Avprod			0.076				0.095	
			(0.132)				(0.117)	
Pcperi			0.314**				0.314***	
			(0.123)				(0.121)	
Elecappli			-0.055				-0.004	
			(0.131)				(0.127)	
Teleprod			0.013				-0.025	
			(0.149)				(0.141)	
Eleccompo			-0.313**				-0.369***	
			(0.126)				(0.122)	
Photoequip			-0.239				-0.184	
			(0.236)				(0.232)	
_cons			-2.059***				-2.050***	
			(0.118)				(0.118)	
Selec. model 2 (Inno):								
Size				0.021				0.025
				(0.041)				(0.041)
Compet_md				0.471***				0.811**
				(0.095)				(0.390)
Compet_st				0.358**				0.721*
				(0.162)				(0.378)
Manuf				0.654***				0.349
				(0.095)				(0.252)
_cons				-0.096				-0.150
				(0.104)				(0.407)
rho			0.524	1.000***			1.000	0.987*
			(0.724)	(5.34e-11)			(0.001)	(0.036)
Wald test (rho=0)			0.34	16.23***			0.01	3.30*
Obs.	87	69	4448	83	69	69	4448	83
Censored obs.			4379	14			4379	14
Uncensored obs.			69	69			69	69
Wald test (full model)	1.44	7.15	2.58	1.28e+06***	0.79	10.21	13.49**	11.85*

Notes: ***/**/* refer to 1%/5%/10% significance level. One-tailed tests are applied for policy-related independent variables and two-tailed tests for variables of firm characteristics in outcome models. In selection models, two-tailed tests are applied. Numbers in parentheses refer to robust standard errors. Instead of 'rho', Stata directly estimated the inverse hyperbolic tangent of 'rho', called '/athrho'. The significance level of 'rho' shown here is for '/athrho', from which 'rho' was derived.

Table 4.4 – Estimation Results of the Role of Active Policy for Academia-Industry Linkages (Estimated Coefficients)

	Source Based on (4) – Table 4.4	Partner Based on (8) – Table 4.4
Pr(Y=1)	0.355	0.027
Policy_md	0.238***	-0.018
	(0.069)	(0.049)
Policy_st	0.259***	0.057*
	(0.088)	(0.039)
Predict_dm	0.117***	0.057
	(0.050)	(0.063)
Size	0.005	0.002
	(0.024)	(0.010)
Age	0.002	-0.002
	(0.005)	(0.002)
Capability	0.001	-0.000
	(0.001)	(0.000)

Notes: To fix the reference point for measuring the corresponding marginal effects, dummy variables in the outcome models are set to be zero, the other independent variables are set to be at their mean levels. Marginal effects of dummy variables are based on discrete value change from 0 to 1. Marginal effects with stars are significant at 10% (*), 5% (**), 1% (***) level. One-tailed tests (based on hypotheses specified in Section 4.2) are applied for the policy-related independent variables and two-tailed tests for the other variables in the outcome models. Numbers in parentheses refer to standard errors.

Table 4.5 – Estimation Results of the Role of Active Policy for Academia-Industry Linkages (Estimated Marginal Effects)

Third, the second policy-related variable (*predict_dm*) is also found to be significantly and positively relevant, at least based on the last but the most relevant model specification for the case in which firms consider academic institutions as innovation sources. This positive relationship suggests that the more predictable the policy changes for firms, the higher the possibility that academic institutions as innovation sources are at least of little importance for them. As shown in Table 4.5, when policy changes become predictable to a reference firm, the probability that it considers academic institutions to be at least little important innovation sources increases from 35.5% to 47.2%. Again, such positive relationship is consistent with our expectation above that the more predictable the changing policies for the HK electronics SMEs, the more time they can invest in managing efficient academia-industry linkages to profit from the changing policies. However, such a significantly positive relationship cannot be found in any model specification for the case of academic institutions as innovation partners.

The lower relevance of both policy-related variables for firms' decisions to cooperate with academic institutions as compared to source from academic institutions does not mean that policies promoting academia-industry cooperation do not work in the case of the HK electronics SMEs. The low relevance may rather be attributed to the distance-induced communication problems mentioned above. In addition, it may also be partially attributed to the fact that policies to promote innovation cooperation were implemented later in HK. In addition, it can also be attributed to potentially higher costs and risks generally embedded in large innovation cooperation projects and the potentially higher technological requirements placed on firms in these projects, which force firms to think and plan more thoroughly before they start the projects and to cooperate with academic institutions. The finding that the two policy variables proxing firms' perception of HK policy change matter, to some extent, for firms' decision to source from or cooperate with academic institutions is consistent with related studies investigating policy impact in the other economies in East Asia (e.g. Eriksson, 2005; Lin et al., 2010) and it is in line with Rubenstein et al. (1977) that the expected policy impact may differ among firms with different policy perceptions as well.

Finally, the three firm characteristics considered (size, age and capabilities) do not seem to matter for whether HK companies consider academic institutions to be important innovation sources or innovation partners, irrespective of model specification considered. This result differs from results found in prior studies conducted in Western countries in which younger firms and firms with certain technological capabilities were found to be more willing or more capable in engaging in academia-industry linkages, while the role of firm size was less clearly idenfitied. Such a low relevance of firm characteristics in HK may, on the one hand, be just a result of limited sample size and thus limited variability of the corresponding variables. On the other hand, it may be attributed to the fact that most HK firms started to innovate only quite lately. When they start to innovate, HK firms, regardless of their different characteristics, probably tend to have similar attitudes regarding innovating with academia institutions, thus making it difficult to clearly identify the relationships between firm characteristics and different academia-industry linkages at this stage.

Our findings that perceived changes in government's policies towards more active innovation promotion may have positive effects on HK electronics SMEs' tendencies to source from or cooperate with academic institutions for innovation purposes suggest that the low importance of academic institutions as innovation sources or innovation partners found in Section 4.5.2 may also be attributed to time lags between the implementation of policies and the full unfolding of their potential effects. However, it is worth noting that firms' unawarenemess of knowledge supplied by academic institutions and potential mismatches between academic knowledge supply and the real needs of firms may also contribute to the currently low relevance of academic institutions as innovation sources or partners for firms. Improving the communication channels between academic institutions and firms may be then substantial in this case.

4.6 Conclusion

Academia-industry linkages are often argued to be advantageous for innovation performance and for sustaining economic growth. Given universities' potentially positive role for supporting industrial innovation, the finding in Chapter 3 that industrial patenting success is strongly determined by firms' own R&D engagement but less related to the accessible academic knowledge causes some concern as to impediments hindering firms from more intensively interacting with universities for innovation. Based on the NIS literature and Bozeman (2000), one may expect that different (perceptions of) innovation policies may affect companies' engagement in different academia-industry linkages differently.

HK is a highly interesting case for investigating the role of different innovation policies for firms' innovation incentives in general and their engagement in academia-industry linkages in particular. This chapter attempted to analyse available statistical and survey data to gain more insights into the potential role of recently more active policy implemented by the HK government for firms' innovation incentives and their willingness to engage in intensive interactions with academic institutions for innovation.

To do so, it analysed, firstly, official statistics on the general development of innovation intentions and academia-industry linkages of HK firms over the past years covering the periods before and after the return of HK back to China and the HK government' role transformation from a mere institution provider to a more active innovation promoter. Secondly, it analysed an original survey dataset to investigate the current status of the HK electronics SMEs with respect to their innovation activities and their engagement in different academia-industry linkages, namely for using academic institutions as training bases, as innovation sources and as innovation partners. Corresponding official statistics were considered for comparison. Finally, it estimated two groups of probit models to investigate the role of changing innovation policies perceived by the HK electronics SMEs for their decisions on sourcing innovation-related technologies and knowledge from and cooperating with the academic institutions for their innovation activities, respectively.

Findings from the official statistics provided some support that innovation engagement and innovation intensity in HK has increased over the period from 1995 to 2007 and the growth in innovation investment and in innovation intensity has been stronger in the period after the initiation of active innovation policy in 1997 than before that year. Among all three types of innovators considered, HK firms have been much more strongly motivated for innovation than universities or research institutes. HK firms did not just increase their investment in their own in-house R&D activities over time but also seemed to intensify their interaction with academic institutions for innovation.

Findings from the statistical survey analysis suggested that innovation activities are gaining in importance for the HK electronics SMEs. Regarding academia-industry linkages, we found, however, that academic institutions do not yet play important roles as innovation sources or innovation partners for HK electronics SMEs compared to other potential innovation sources or innovation partners. Still, relatively more HK electronics SMEs were found to consider academic institutions as important innovation sources compared to the HK innovative firms as a whole. There was, additionally, some indirect evidence that HK electronics SMEs seem to rather appreciate academic institutions as training bases of highly-qualified labour for supporting their innovation activities.

The still comparatively low relevance of academic institutions as innovation sources or innovation partners for the HK electronics SMEs should not, however, be interpreted as implying that policies fostering innovation in general and promoting academia-industry linkages in particular perceived by the HK electronics SMEs are not effective at all. The estimation results suggested, in contrast, that changing policies (perceived by the HK electronics SMEs) may affect positively SMEs' willingness to source innovation-related technologies and knowledge from academic institutions, while the policy effects on their tendency to cooperate with academic institutions seem to be weaker though still positive. The lower positive effect in case of cooperation with academic institutions may be, to large extent, attributed to distance-induced communication problems which hinder the HK electronics SMEs innovating in the PRD from intensively cooperating with academic institutions in HK in general.

The difference between the statistical finding of low importance of academic institutions as innovation sources or innovation partners and the finding of seemingly positive policy effects in this regard may be attributed to time lags of potential policy effects or/and mismatches between the knowledge and technologies provided by academic institutions and the real needs of firms as well. How such communication and mismatch problems can be efficiently solved would be substantial for facilitating the unfolding of the potential effect of the more active innovation policy implemented in HK since 1997 on economy-wide innovation and further economic development in HK. The HK experience with policy changes to more actively promote innovation and academia-industry linkages may additionally provide some policy implications for innovation policy in mainland China. However, one may still need to bear in mind that the investigation in this chapter was based on a firm-level analysis with a limited number of firm samples. That firms from industries which have not been selected as focus industries for innovation promotion by the HK government were not integrated into the firm survey stays as a deficiency in providing sample counterparts for robustness check of the results. Future research may try to expand both the industrial covering and the survey sample size and to continuously conduct the survey for years to build up a reliable panel dataset for a more comprehensive policy analysis.

4.A Appendix

Three additional tables are presented here to provide more information related to Chapter 4.

A. <u>Innovation strategies and innovation activities</u>

1. **How important are the two following strategies for your company? (1 - very important, 5 - not important)**
   12345 Cost reduction   12345 Increase innovation activities

2. **Does your company carry out any innovation activities? How important are the following innovation activities for your company? (1 – very important; 5 – not important)**
   ☐ The company does not carry out any innovation activities *(go to other survey questions)*
   12345 Product innovation   12345 Process innovation
   12345 Organisational innovation   12345 Marketing innovation

3. **How important are the following sources for your company to obtain innovation-related technology and know-how? (1 - very important, 5 - not important)**
   12345 Own R&D department   12345 Own Production-related departments
   12345 Own Marketing-related departments   12345 Universities or research institutes
   12345 Other companies or individuals (e.g. competitors, suppliers, customers)
   12345 Buying existing products or technologies 12345 Hiring of highly-qualified employees
   12345 Other sources: ______________________

4. **a) How important is PRD for your company's innovation activities? (1 – very important, 5 – not important)**
   ❑ No innovation activities in PRD *(go to other survey questions)*
   Importance of PRD: 12345
   b) Which city in PRD is the most important innovation location for your company? ____

5. **How important are the following criteria for your company to perform its innovation activities in this city in PRD? (1 - very important, 5 - not important)**
   12345 Qualified labour and/or researchers
   12345 Innovation structure (e.g. universities, science parks, venture capital companies)
   12345 Proximity to other companies in the same or related sectors
   12345 Tax exemptions or preferential treatments from local government
   12345 Few governmental regulations or rules on innovation activities
   12345 Well-established legal systems
   12345 Personal and/or family ties
   12345 Others:______________________________

6. **Does your company apply the following forms to organise its innovation activities in PRD? If yes, how important are they? (1 - very important, 5 - not important, 0 – not applied)**
   12345-0 Acquisition of licenses and/or innovations   12345-0 Reverse engineering
   12345-0 Own R&D and innovation activities   12345-0 * Cooperation with partners
   * *if applied,* Who are partners? ☐Universities/Research institutes ☐Suppliers
   ☐Customers ☐Others

Note: Executives interviewed were informed clearly about the Likert scales used in the survey.

Table 4.A.1 – HK Company Survey Questionnaire (Relevant Part)

B. <u>Other relevant questions</u>

1. **How many employees were/are employed in your company in total?**
   31/12/2001: HK______ PRD______ Other______
   31/12/2006: HK______ PRD______ Other______
   Next 5 years: HK + 0 − PRD + 0 − Other + 0 –

2. **In what year did your company start its operations in HK and PRD? :**
   HK _________ PRD __________

3. **Please indicate the share of your company's sales in 2006 according to the following categories.**
   ___% Manufacturing arm of parent company: products manufactured by your company according to design specifications provided by parent company or associate in the corporate group
   ___% Original equipment manufacturing (OEM): products manufactured by your company according to design specifications provided by buyers
   ___% Original design manufacturing (ODM): products developed and designed by your company according to performance requirements of buyers
   ___% Original brand manufacturing (OBM): products developed and designed by your company and sold under your own brand

4. **Please, assess for the last 5 years, how predictable changes of the following industry conditions have been for your company. (1 – very predictable, 5 – not predictable)**
   12345 Price of products
   12345 Volume of demand
   12345 Quality of products
   12345 Delivery times
   12345 Availability of resources and suppliers
   12345 Availability of labour
   12345 Governmental regulations and policies

5. **How has the intensity of competition changed for your company over the last 5 years?**
   ☐ strongly increased ☐moderately increased ☐ unchanged
   ☐ moderately decreased ☐ strongly decreased

Note: Executives interviewed were informed clearly about the Likert scales used in the survey.

Table 4.A.1 (continued) – HK Company Survey Questionnaire (Relevant Part)

	Variable description	Mean[a]	Std. Dev.[a]	Min.[a]	Max.[a]	Obs.[a]
Source	Academic institutions as at least a little important innovation sources (1) or not (0)	0.648	0.480	0	1	88
Partner	Academic institutions as innovation partners (1) or not (0)	0.071	0.259	0	1	70
Policy_md	Policy as a factor considered for choosing inno. location (a little or normally important)	0.471	0.503	0	1	70
Policy_st	Policy as a factor considered for choosing inno. location (important or very important)	0.186	0.392	0	1	70
Predict_dm	Policy was predictable or very predictable in the past five years	0.220	0.416	0	1	100
Size	Number of employees in total in 2006 in nat. log	4.523	1.920	0	8.179	102
Age	Age of company since its start in HK (till 2007)	14.039	9.280	1	40	102
Capability	Share of sales realised in ODM and OBM way	34.208	36.466	0	100	101
Responding	Responding survey questionnaire (1) or not (0)	1	0	1	1	102
		(0.023)	(0.149)	(0)	(1)	(4481)
Labequip	Producing laboratory and scientific equipments (1) or not(0)	0.020	0.139	0	1	102
		(0.008)	(0.087)	(0)	(1)	(4481)
Avprod	Producing audio-visual products (1) or not (0)	0.333	0.474	0	1	102
		(0.227)	(0.419)	(0)	(1)	(4481)
Pcperi	Producing computer and peripherals (1) or not (0)	0.245	0.432	0	1	102
		(0.127)	(0.332)	(0)	(1)	(4481)
Elecappli	Producing electrical appliances (1) or not (0)	0.186	0.391	0	1	102
		(0.166)	(0.372)	(0)	(1)	(4481)
Teleprod	Producing telecom products (1) or not (0)	0.127	0.335	0	1	102
		(0.120)	(0.325)	(0)	(1)	(4481)
Eleccompo	Producing electronic/electrical components and accessories (1) or not (0)	0.441	0.499	0	1	102
		(0.607)	(0.488)	(0)	(1)	(4481)
Photoequip	Producing cameras and photographic equipments (1) or not (0)	0.039	0.195	0	1	102
		(0.052)	(0.222)	(0)	(1)	(4481)
Inno	Carrying out innovation activities (1) or not (0)	0.863	0.346	0	1	102
Compet_md	Facing moderately increasing competition pressure (1) or not (0)	0.265	0.443	0	1	102
Compet_st	Facing strongly increasing competition pressure (1) or not (0)	0.647	0.480	0	1	102
Manuf	Being manufacturer (1) or not (0)	0.902	0.299	0	1	102
		(0.914)	(0.280)	(0)	(1)	(4481)

Note: [a]Numbers in parentheses refer to the corresponding statistics for the whole population of the HK Electronics SMEs from the TDC data bank. Source: Own HK Company Survey 2007.

Table 4.A.2 – Variable Description and Basic Descriptive Statistics of Variables Considered in the Estimated Regression Models

	Policy_md	Policy_st	Predict_dm	Size	Age	Capability
Policy_md	1 (70)					
Policy_st	-0.451*** (70)	1 (70)				
Predict_dm	-0.057 (69)	0.072 (69)	1 (100)			
Size	-0.239** (70)	0.161 (70)	-0.082 (100)	1 (102)		
Age	-0.148 (70)	0.050 (70)	-0.126 (100)	0.270 (102)	1(102)	
Capability	-0.116 (69)	0.032 (69)	-0.071 (100)	-0.087(101)	-0.065(101)	1(101)

Note: Number in parenthese refers to the number of observations. ***/**/* refer to 1%/5%/10% significance level.

Table 4.A.3 – Pairwise Spearman Correlation Coefficients among Explanatory Variables Considered in the Estimated Probit Outcome Model

5 Conclusion

China's progress over the past three decades of economic reform has not been reflected in its on average two-digit economic growth rate and in its intensified integration in world economy only. China's change in its policy focus towards more upgrading and innovation indicates its progress in policy decision-making process which more and more takes into account the potential impact of contemporary and future economic development of other world economic players on the Chinese economy. Both the Chinese central government and local governments have implemented various innovation-friendly policies to encourage firms, universities and research institutes to make more contribution to research and upgrading process in China. As a result, a strong increase in research and development (R&D) expenditure and innovation outcomes such as patent applications from all kinds of innovators over time can be observed. Against the traditional division of labour, in which universities have been mainly responsible for research activities and firms for production, one may expect that universities' knowledge supply and their interaction with firms play a crucial role for firms to realise outstanding innovation performance. The expectation that universities can be significant knowledge sources for firms' innovation activities finds additional support from the empirically positive findings in the related literature, though most of the studies focused on Western economies.

This dissertation aimed to investigate firms' innovation activities in China, the role of universities in this regard and whether firms' willingness to engage in academia-industry linkages can be actively promoted through relevant policy. It applied a three-step approach for the investigation. Each step served to deal with a sub-question derived from the overall research aim and for different sub-questions various datasets were analysed, using different econometric techniques. Results of the three-step analysis were presented in Chapter 2 to 4.

As the first step, Chapter 2 investigated the role of firms' own R&D engagement and the relevance of knowledge transferred from different sources for their various innovation results. The investigation was based on a firm-level dataset collected by our own PRD (Pearl River Delta) Company Survey in late 2007 in China. Estimation results showed that firms' own R&D engagement is significantly relevant for firms to carry out some but not all kinds of innovation outcomes. Their own R&D engagement was found to matter significantly for firms' success in producing innovative products, increasing their innovation sales and for patenting results but it is not relevant for firms' performance in realising process innovation. In addition to the identified different relevance of own R&D engagement, knowledge transferred from different sources were also found to be of different significance as innovation inputs for firms performing different kinds of innovation activities, that is consistent with our base literature such as Criscuolo et al. (2005) and Wagner (2006). While firms' OEM (original equipment manufacturing) customers were found to be significantly relevant as knowledge sources for firms' performance in process innovation, universities and research institutes were found to play a significant role for determining firms' patenting activities. Despite such a positive role of university research for firms' patenting activities, only few firms interviewed indeed evaluated universities and research institutes as important or very important knowledge sources for them. Taking into consideration the survey finding that firms prefer to hire highly qualified workers as their knowledge sources for supporting their innovation activities in general, the estimation results seem to suggest that firms do not yet sufficiently recognise the benefits they may obtain through sourcing knowledge directly from universities. Instead, it seems that they tend to rely more intensively on hiring highly qualified workers as knowledge transmitters to gain access to the reservoir of academic knowledge.

Chapter 3 deepened the analysis in Chapter 2 by investigating the role of university research for industrial patenting results in more detail instead of investigating the determinants of industrial innovation in China in general. In doing so it extended the analysis of Chapter 2 in the following three aspects: regional and geographic aspect, sectoral aspect and the aspect of university research quality. The analysis was based on a provincial panel dataset from China for the years from 2000 to 2008. To measure firms' accessibility to university research, logsum indicators based on city-level statistics were calculated, taking into account both firms' geographic distance to universities and university research quality.

The baseline estimation model was derived from the Griliches-Jaffe knowledge production function framework which was used in several comparable studies for the US and some selected European countries. The estimation exercises starting from estimating the baseline model to estimating the extended models for robustness check can be summarised in the following five steps. Firstly, we estimated the baseline models with different sets of explanatory variables using both Within- and RE-estimators. Secondly, we dealt with the potential endogeneity with respect to the industrial R&D

based on instrumental variable analysis. Thirdly, we used alternative values of the distance decay parameter to check the robustness of our main findings regarding the role of firms' proximity to universities for their patenting results. Fourthly, we additionally considered the aspect of university research quality in our accessibility measure, based on two quality concepts. Finally, we used alternative values of the quality decay parameter and three different variables to proxy the university quality to check the robustness of the findings regarding the quality-adjusted accessibility measures.

Results in Chapter 3, despite its extension in the abovementioned three aspects in the analysis, were consistent with the findings in Chapter 2. We found that university research matters for industrial patenting results, but firms' own R&D expenditure seems to still play a much more substantial role for their patenting activities. The positive effects of universities on industrial patenting activities were found to decrease over distance between firms and universities, however. This finding of positive spatial academic research effects on industrial patenting results is consistent with the previous literature for Western economies (e.g. Jaffe, 1989; Anselin et al., 1997 & 2000). Differentiating industrial patenting results in two groups by technological complexity, results in Chapter 3 showed that such positive spatial effects of university research are only significant for firms' non-invention patenting results but not for their technologically more advanced invention patenting applications. Moreover, considering quality-adjusted accessibility measures in the extended estimation models showed that geographic proximity of firms to universities still dominates over university research quality in contemporary China for determining the relevance of university research for industrial patenting results.

The relative low relevance of university research compared to industrial R&D engagement for industrial patenting activities and the finding that firms' proximity to university research – with high quality or not – is even insignificant for industrial invention patenting results are surprising, if one takes into account the traditional division of labour among universities and firms in China. Based on the concept of national innovation system we may expect that governments through adequate policy can remove (partially) institutional impediments to encourage firms to engage in academia-industry linkages more intensively. Chapter 4 used Hong Kong (HK) with its specific historical background as an example to learn more about whether more active innovation policy emphasising academia-industry linkages may have certain potential on positively affecting firms' innovation intention in general and on encouraging innovative firms to engage in academia-industry linkages more intensively in particular.

The analysis in Chapter 4 was based on HK official statistics as well as on a firm-level dataset collected by our own HK Company Survey in 2007. HK official statistics showed that HK firms have engaged more intensively in both innovation activities and interactions with universities and research institutes for innovation since the late 1990s when the HK government gradually transformed its role from being a provider of business-friendly institutions to support economic development to being a more active innovation promoter. Our survey results showed, consistent with official statistics, that HK (electronics) firms still prefer to obtain innovation-related technologies and knowledge from non-academic sources and they tend to cooperate with other non-academic innovators for supporting their innovation activities. However, compared to HK firms in general HK electronics firms – one of the focus groups of active innovation policy in HK – were found to be more willing to source innovation-related technologies and knowledge from universities and research institutes.

To gain more insights into the potential role of changing innovation policy in HK for HK electronics firms' willingness to engage in academia-industry linkages directly, empirical models were estimated using probit estimation techniques. The estimation results suggested that changing policies (perceived by the HK electronics firms) may indeed have positive influence on HK electronics firms' willingness to source innovation-related technologies and know-how from and to cooperate with universities and research institutes, although the positive influence was not found to be always significant in the estimation models.

From the three-step analysis from Chapter 2 to Chapter 4 we found that firms in China may indeed profit from the knowledge reservoir of universities, especially those located close to firms. But till now it seems that firms do not (yet) sufficiently recognise the role of universities as knowledge providers who may support their innovation efficiency and innovation performance. Although active innovation policy focusing on promoting not only innovation activities in general but also the intensity of academia-industry linkages in particular was found, as shown in the HK case, to have positive influence potential on encouraging firms to innovate and to interact with universities and research institutes more intensively, it seems that such positive influence is still small in size. The difference between the findings of low relevance of universities as innovation sources or innovation partners and the finding of positive policy effects may be attributed to time lags of potential policy effects, still existent deficiency in transportation and communication infrastructure or/and mismatches between the knowledge and technologies provided by universities and the real needs of firms.

Some policy implications may be derived based on the findings in the last three chapters. First of all, it is essential for policymakers from mainland China and HK to identify the main (institutional) factors impeding firms to engage in academia-industry linkages intensively to ensure that governmental policies deal with the real challenges for innovation. The finding that spatial academic research effects were especially large for technologically less advanced (non-invention) patenting results may serve as a starting base for exploring and investigating significant impediments against academia-industry linkages for encouraging especially industrial invention innovation activities. In case that mismatches between knowledge and technologies provided by universities and the real needs of firms are indeed the major reason hindering firms from doing so, governmental policies which only provide financial stimulus for academia-industry cooperation may have only little impact. Instead, the central and local governments may go one step back to financially support interest groups to organise discussion platforms, exhibitions and technical markets regularly to encourage a more direct communication and idea exchanges among industrial innovators and university researchers.

Moreover, governments may try to further improve basic infrastructure such as the infrastructure system supporting transportation as well as distance communication to help innovators from both industrial and academic sites to more easily have face to face discussion to foster further cooperation. Last but not least, future research may attempt to establish a large-scale panel dataset covering a greater number of firms from various industries and build a large-scale panel dataset on academia-industry linkages at the university researcher level. The establishment of these datasets is expected to help investigate the determinants influencing the incentives and willingness for academia-industry linkages from a broader industrial aspect as well as from the academic aspect in a more systematic and quantitative way. Results obtained are expected to help policymakers further improve innovation and/or higher education policies to encourage industrial innovators as well as university researchers to communicate with each other more intensively for fostering innovation; thus for supporting the long-term economic growth.

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Ich erkläre hiermit an Eides Statt, dass ich meine Doktorarbeit „Determinants of Industrial Innovation in China and the Role of University Research“ selbständig und ohne fremde Hilfe angefertigt habe und dass ich alle von anderen Autoren wörtlich übernommenen Stellen, wie auch die sich an die Gedanken anderer Autoren eng anlehnenden Ausführungen meiner Arbeit, besonders gekennzeichnet und die Quellen nach den mir angegebenen Richtlinien zitiert habe.

Wan-Hsin Liu

Kiel, Juli 2012