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Technological diversification in China: Based on Chinese patent analysis during 1986-2011

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Key words technological diversification and specialization; patents; China; R&D investment structure; size-diversification relationship

Introduction

Technological diversification is an intrinsic part of economic take-off and development, signaling the shift from extensive development in traditional industrial sectors towards more technologically intensive and innovative sectors. It can occur at the country level through the replacement of older traditional firms by new ones embodying new technology in innovative sectors. Or it can occur at the firm level as firms shift their technologies from one (traditional, older field) to another (newer, innovative field). Technological diversification in a country can occur simultaneously with increasing technological specialization between firms or with less specialization between firms if there is technological diversification at the firm level.

Technological diversification has been studied as a topic in the economic and managerial literatures (Archibugi & Pianta, 1992; Breschi, Lissoni, & Malerba, 2003; Cantwell & Vertova, 2004; Chen, Jang, & Wen, 2010; Chen, Shih, & Chang, 2012b; Chiu, Lai, Liaw, & Lee, 2010; Luan, Liu, & Wang, 2013; Piscitello, 2000; Purkayastha, Manolova, & Edelman, 2012). Studies fall into two major groups: at the micro or firm level and at the macro or country level.

At the micro-level research has focused on the motivation driving technological diversification, and the relationship between technological diversification and product diversification, with the related performance implications for firms (Chen et al., 2010; Chen et al., 2012b; Garcia-Vega, 2006; Kim, Lim, & Park, 2009; Leten, Belderbos, & Van Looy, 2007; Miller, 2006; Nachum, 1999; Watanabe, Hur, & Matsumoto, 2005). Chandler (1990) highlighted technological diversification at the firm level as the motor of growth and development of leading US corporations in the first half of the twentieth century. It referred to the shift, using economies of scope such as managerial and R&D departments, across technologies within the firm such as that in Du Pont from gunpowder, to dyes and paints through to drug development. The linkages between technological diversification and product and corporate diversification are complex. Chandler (1962 1977, 1990) stressed their intimate relationship. The literature on corporate diversification has highlighted the benefits from diversification in terms of lower-costs, risk-spreading, and economies of scale and scope (Patel & Pavitt, 1997; Purkayastha et al., 2012; Rumelt, 1974). These issues have been extended to the concept of technological diversification (Cesaroni, 1997; Chen et al., 2012b; Gambardella & Torrisi, 1998; Granstrand & Sjolander, 1990; Kim & Kogut, 1996; Laursen, 1996; Zander, 1997). Granstrand (1990) found that technological diversification is usually more extensive than product diversification. Gambardella and Torrisi (1998) found that the best performing companies were those that focused on their core business in product terms but widened their technological capabilities.

At the country-wide level technological diversification refers to the shift over time by both incumbent firms and new entrant firms from one technological field to more advanced or newer technological fields in newly developing industrial sectors. At the national level, this diversification can be tracked through examining the expansion of technological activities over time. (Breschi et al.,2003). At the macro country- level the literature can be summarized into the following propositions : first, there is a positive relationship between a country's technological size and its diversification, that is, the size-diversification relationship hypothesis (Archibugi et al., 1992). Large countries, by measures of population, GDP or number of patents, tend to extend their technology portfolio into a larger number of technology fields. Second, as countries become more developed technologically, there is a structural shift in this relationship between size and technological diversification at the country level with a marked increase in technological diversification during periods of rapid growth and technological development. In other words not only is there a positive relationship between size and technological diversification, but this relationship becomes more accentuated in periods of rapid technological development and this is particularly the case for large countries. These results in Cantwell and Vertova (2004) are strongly influenced by the observations for the US as the large country driver of this technological development. Third this relationship for the most technologically developed countries shifted markedly towards specialization in the most recent era measured of 1965-1990, driven by international technological specialization through multinational FDI. Countries became more specialized in their different fields of research activities influenced by the location of multinationals (Cantwell et al., 2004).

The literature on technological diversification has focused almost exclusively on developed countries and firms located in those countries with few exceptions. (Bell & Pavitt, 1993). This study updates this understanding of technological diversification to see whether these relationships hold in the case of China and its rapid technological growth. It compares and enriches findings relating to developed countries, with an investigation of the evolution of technological diversification in China from 1986 to 2011. It examines whether the size-diversification hypothesis holds in the Chinese context and looks for structural changes in that relationship between size and technological diversification. It suggests a possible explanation for these structural changes.

China has only fairly recently taken off in terms of a boom in technological activity, as manifest in the explosion in patenting since the mid-1990s (Hu and Jefferson 2009). Other estimates suggest that China's patent activity grew by 470% in the 10 years to 2006 (Ma et al 2009). This has partly been driven by reform in the intellectual property laws and also by the government-fuelled initiatives to upgrade the structure of the economy away from lower-value-added parts of manufacturing towards technologically intensive and innovative sectors. The boom in Chinese patenting reflects in part a response to these government incentives, but also marks a rise in the strategic use of patenting to carve out trajectories and to signal commitment to enter into collaborative activities in the scientific and technological arenas with other countries that are intrinsic to this kind of development (Ma et al 2009).

We place China's patenting activity in the context of patenting and technological diversification by the other BRIC (Brazil, Russia, India, China) countries compared with the US (Athreye and Prevezer 2008). Athreye and Prevezer (2008) compare patent applications of the BRIC countries with the US, and highlight the evolution in technological fields of Chinese and Indian patents. Chinese patenting started from a relatively low base but has been increasing to 2006 very markedly. In terms of its distribution across technological fields, one notes the demise of more traditional fields and the rise particularly of electrical and computing technological fields. These observations are based on USPTO patent data which are incomplete in regard to Chinese patenting, whilst allowing comparison between BRIC and developed countries.

This current work is based on a new dataset taken from the Chinese patent office, SIPO, to look more comprehensively at the pattern of Chinese patenting and its historical evolution since 1986 to 2011, with a database of 3.7 million Chinese patents. It compares technological diversification through three periods of Chinese development with the pattern of diversification found in 8 technologically leading developed countries collectively during their developmental periods from 1890-1914, 1915-1939, 1940-1964 through to their more recent globalization period of 1965-1990 (Cantwell and Vertova 2004). There are several points of interest in this comparison: 1) Does China with its trajectory of state-led innovation and the much more 'Visible Hand' of the Chinese state in terms of policies guiding that trajectory (Liu, Simon, Sun, Cao 2011) follow the same path in terms of relationship between growth of patenting and technological diversification as earlier more market-led trajectories of technological development? 2) What is the relationship between technological diversification and specialization in terms of temporal sequencing? Does one have first diversification and then specialization or can both occur simultaneously? In terms of spatial level of diversification or specialization, does this occur at the country-level or firm-level or regional-level? And 3) what difference does the later entry of China into this process make compared with earlier trajectories in developed countries, and relatedly what is the contribution of Foreign Direct Investment and foreign collaboration in technological diversification or specialization?

Section 2 discusses data and research methods; Section 3 presents results; Section 4 draws out conclusions and discusses implications.

Section 2 Data and methods

The statistical and econometric analysis employed in this study is based on the use of patent statistics as a proxy for China's profile of technological diversification. Prior studies of technological diversification have also been based on patent data. (Archibugi et al., 1992; Chen & Chang, 2012a; Leten et al., 2007). The relative merits and weaknesses of patent statistics have been widely discussed in prior studies (Archibugi & Pianta, 1996; Hagedoorn & Cloodt, 2003; Hausman & Griliches, 1984) where it is demonstrated that patent statistics are a useful indicator of technological activities at both the firm and the country levels. This study thus follows these seminal prior studies and makes use of Chinese patents to form our main dataset.

In China, patents are categorized into three different types: inventions, utility models, and designs. Because the design type implies relatively lower technological advancement and is subject only to a simple application procedure without careful technological examination, we include only invention and utility model types in this study. The time frame used was the period 1986 to 2011 as we are interested in the long-term trajectory of technological diversification and specialization to compare with Cantwell and Vertova (2004). In total, there were 3,705,975 patent applications in this period. An overview of patent applications throughout the observation period is shown in figure 1. All patent data are collected through the China State Intellectual Property Office (SIPO). Although this renders our data not comparable with those taken from the USPTO, as many other comparative studies are, it gives a much more comprehensive picture of patenting activities within China, rather than picking up only those most valuable and internationally competitive patents that are taken out at the USPTO. As our focus is on the domestic trajectory over time, this approach based on the more extensive domestic data was favoured. Patents applied for by foreign organizations in the SIPO were excluded by the identification of the patentees' address in foreign countries. Additionally, some supporting data on China's macro-economy were collected from Chinese Annual Statistics (1985-2012).

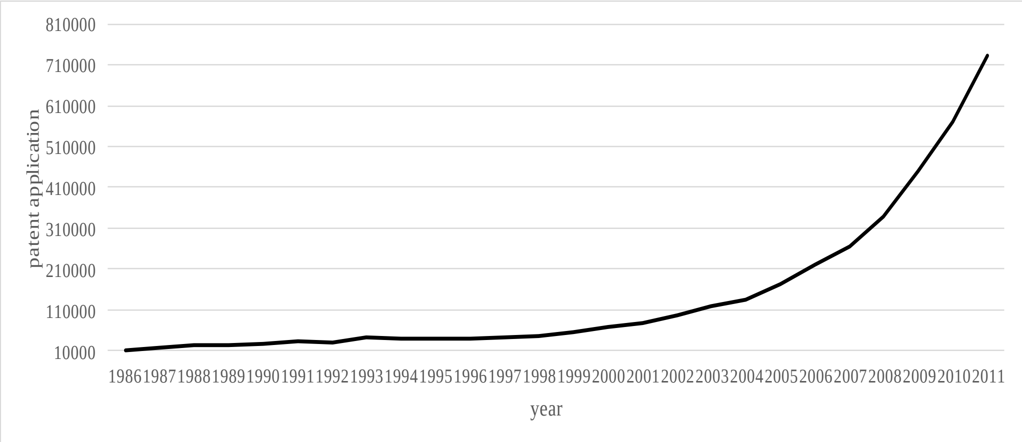

Fig.1. An overview of Chinese patent applications during the period 1986-2011

Since each patent is classified according to the type of technological activity, the original patent classes identified by the OECD can be grouped into 30 technological sectors, collecting together technologically related patent classes (see Appendix A). An overview distribution of China's technological fields (the top ten) in different years is presented in Table 1. As can be seen in Table 1, there is a dynamic change over time in Chinese technology fields, as shown by the ratio of patent applications in a particular field out of total applications. One notes a decline in the importance (as given by the ratio) of Consumer goods and equipment, alongside a rise in Electrical Devices and Engineering.

Table 1. An overview distribution of China main technology areas in 1986, 1990, 2000, and 2011

Year	Technological Field	Ratio
1986	Consumer Goods and Equipment	0.205

	Control and Instrumentation Technology	0.103
	Electrical Devices and Engineering	0.09
	Civil Engineering, Mining, Architecture	0.059
	Transportation	0.053
	Medical Technology	0.05
	Heat Treatment and Equipment	0.05
	Mechanical Components	0.04
	Machine Tool	0.038
	Engine ,Pump, Turbine	0.036
1990	Consumer Goods and Equipment	0.189
	Civil Engineering, Mining, Architecture	0.081
	Control and Instrumentation Technology	0.078
	Electrical Devices and Engineering	0.074
	Medical Technology	0.059
	Transportation	0.056
	Heat Treatment and Equipment	0.056
	Mechanical Components	0.045
	Engine, Pump, Turbine	0.04
	Hauling & Printing	0.038
2000	Consumer Goods and Equipment	0.126
	Civil Engineering, Mining, Architecture	0.081
	Heat Treatment and Equipment	0.061
	Electrical Devices and Engineering	0.061
	Transportation	0.059
	Medical Technology	0.056
	Biotechnology	0.054
	Control and Instrumentation Technology	0.052
	Hauling & Printing	0.046
	Mechanical Components	0.04
2011	Electrical Devices and Engineering	0.105
	Consumer Goods and Equipment	0.101
	Control and Instrumentation Technology	0.083
	Civil Engineering, Mining, Architecture	0.067
	Machine Tool	0.056
	Hauling & Printing	0.052
	Mechanical Components	0.044
	Chemical Engineering	0.043
	Medical Technology	0.042
	Transportation	0.037

Because we are interested in the evolution of Chinese technological diversification, in line with previous studies (Liu et al 2011), we split the period of 1986-2011 into three historical periods following China's important events and its "five-year" development plans[1] in this period:

- The pre-marketization period (1986-1990)
- The rapid-marketizaiton period (1991-2000), this period is further divided into two sub-periods (1991-1995, 1996-2000).
- The globalization period (2001-2011), this period is also further divided two sub-periods (2001-2005, 2006-2011).

The pre-marketization period dates from before the time of China's major reform and opening policies, when it established some relevant institutions, including the institution of the patent system in the mid-1980s. In this period, China was guided by its long established central planning system. Deng Xiaoping's southern tour speech in 1992 marks the start of China's more rapid marketization process, with its increasing emphasis on the market system replacing its planning system. In 2001, China joined the World Trade Organization (WTO), as a push towards increasing Chinese integration into the international trading system. These different periods display differences in a number of characteristics in China such as a reweighting of technological and research activity away from government-run and controlled institutes towards enterprises,

[1]Every five-year, Chinese governments will issue a development plan, including economic, social, technological and all most other related fields. These plans have become an important instruction guiding its development for governments and other related entities at all levels. Our observation thus started from the seventh five-year plan (1986-1990), and onwards to the eleventh one (2006-2010, in this study, extended to 2011 for a full use of our data).

and with an increasing emphasis on foreign relationships influencing technological development (Sun and Liu 2010).

Following prior studies, (e.g. Zander, 1997), this study uses the entropy measure to proxy technological diversification. The entropy measure takes into account both the number of patents in which a country might be active, as well as the relative distribution of patents across the patent classes, the formula is presented as follows,

$$diversity = \sum_{i=1}^{30} P_i \ln 1 / P_i$$

Where P_i represents the share of Chinese patents accounted for by the ith patent. The value of the entropy measure ranges between zero and $\ln n$, where a value of zero means that a country is concentrating on one technology only and a value approaching $\ln n$ presents a firm with an even distribution of patents across the n technologies. This is equivalent to the measure used in Cantwell and Vertova (2004) which they label 1/CV which is related to the inverse of the Herfindahl index of concentration. High values of 1/CV represents an even distribution of a country's profile across different technological sectors, whereas low 1/CV means concentration or specialization on relatively few technological fields. Equivalently here, low entropy signals specialization or concentration, whereas a value approaching ln n means a diversified portfolio of technologies.

Results

Historical evolution of China's technological diversification

According to this entropy measure of technological diversification, Figure 2 shows an increasing level of technological diversification since 1986, which peaks in 2006, and declines slightly to 2011.

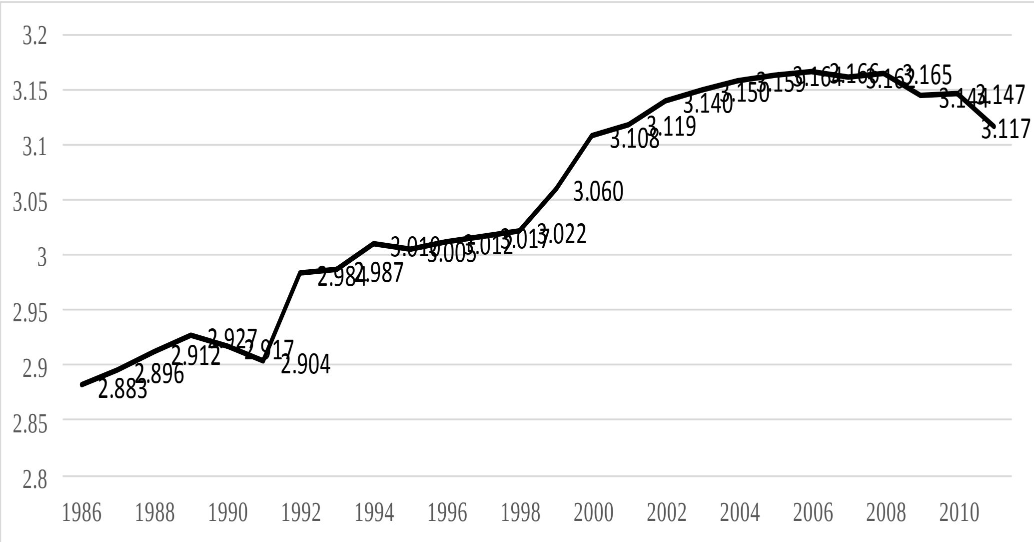

Fig.2. Historical evolving trend of Chinese technological diversification during 1986-2011

The results split into the different historical periods are presented in table 2. It is found that in the pre-marketization period, technological diversification is relatively lower, rising on average through to the globalization period .

Table 2 Technological diversification in historical periods

	Total patent applications	Technological diversification
Pre-marketization（1986-1990）		
（1986-1990）	100245	2.91
Rapid-marketization（1991-2000）		
（1991-1995）	182142	2.98
（1996-2000）	246366	3.04
Globalization（2001-2011）		

（2001-2005）	600620	3.15
（2006-2011）	2576602	3.15

This compares with the Cantwell-Vertova results for the US, Germany, UK, Italy, France, Japan, Switzerland and Sweden combined of diversification indices of 2.5 in 1890-1914, rising to 2.8 in 1915-1939, peaking at 3.5 for the period 1940-1964 and declining to 2.6 in the period 1965-90. Archibugi et al (1992) corroborates this finding, presenting a very similar increasing trend in diversification followed by a peak and decline in a period of rapid internationalization. Our results for China show a rather similar trajectory of increasing technological diversification peaking in 2006 at slightly lower levels of diversification, and declining slightly after that. We might expect further declines in diversification and increasing specialization to continue to occur.

We probe our Chinese results further by decomposing China into three broad regional areas: the east coastal region, the middle region and the western region. There is a widely acknowledged disparity between these three Chinese groups of regions in terms of social and economic endowments, and institutional differences (Sun and Liu 2010; Zhang, Sun, Delgado, Kumbhakar 2012; Altenburg, Schmitz, & Stamm, 2008; Hong & Su, 2013; Li, 2009; Sun, 2000). We divide the macro patent data into these three regions, and calculate the technological diversification for these three regions separately, see figure 3. Detailed information and the average value in the historical three periods are shown in Table 3. From Table 3 we see a huge disparity in technological size between the regions, with the Eastern provinces well in advance of the middle region, which in turn is well in advance of the western region.

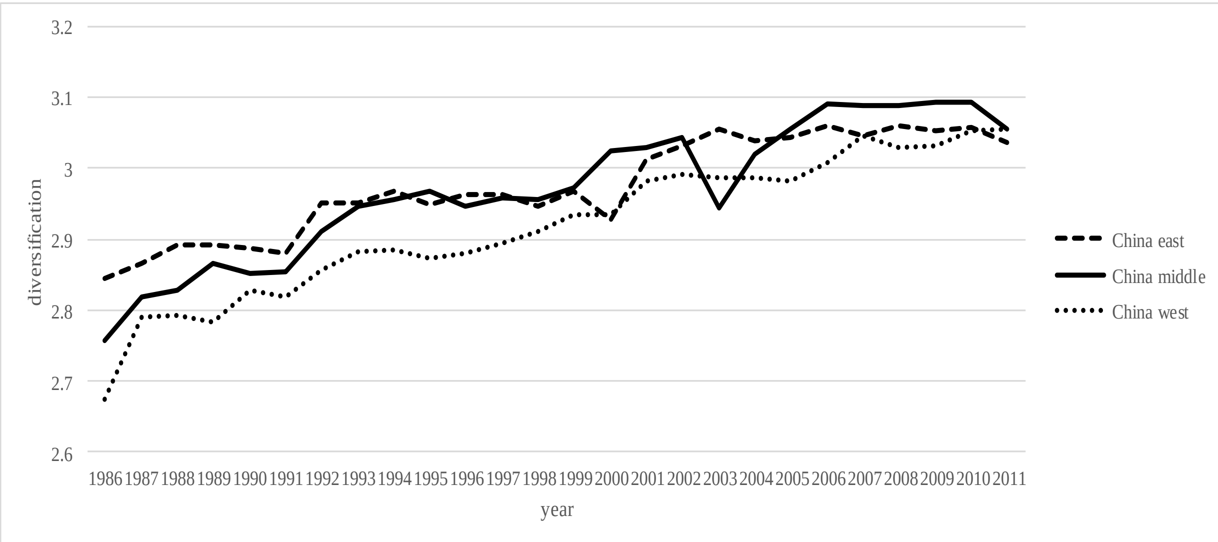

Fig.3. Technological diversification in China three major regions during 1986-2011

Nevertheless in Figure 3 and Table 3 we find that in terms of technological diversification, there is an upward trend in all three regions, with the western region only slightly below the other two in terms of technological diversification. The gap between the western and the other two has closed significantly in the recent globalization period.

Table 3 Technological diversification in both regional and historical dimensions

	China east	China middle	China west
Pre-marketization（1986-1990）			
Total patent applications（1986-1990）	62836	27526	17326
Percentage of nation （1986-1990）	58.35	25.56	16.09
Technological diversification (TD) (1986-1990)	2.89	2.82	2.75
Standard variation of TD (1986-1990)	0.08	0.07	0.16
Rapid-marketization（1991-2000）			
Total patent applications（1991-1995）	106877	44408	30857
Percentage of nation（1991-1995）	58.68	24.38	16.94
Total patent applications（1996-2000）	154792	54938	36636
Percentage of nation（1996-2000）	62.83	22.3	14.87
Technological diversification (1991-1995)	2.94	2.93	2.86
Standard of TD (1991-1995)	0.07	0.06	0.10
Technological diversification（1996-2000）	2.95	2.97	2.91
Standard variation of TD（1996-2000）	0.12	0.06	0.12
Globalization（2001-2011）			
Total patent applications（2001-2005）	431794	102302	66524
Percentage of nation（2001-2005）	71.89	17.03	11.08
Standard variation of TD（2006-2011）	1916440	387806	272356
Percentage of nation（2006-2011）	74.38	15.05	10.57
Technological diversification（2001-2005）	3.04	3.02	2.99
Standard variation of TD（2001-2005）	0.10	0.12	0.13
Technological diversification（2006-2011）	3.05	3.08	3.04
Standard variation of TD（2006-2011）	0.09	0.04	0.09

Overall these results suggest a very similar developmental pattern through technological diversification as has happened in the past in the technologically leading countries and remarkably little difference between the three regions in terms of their technological diversification in each period despite the huge gap in technological size between regions.

Re-examination of size-diversification in China context

Larger countries have a propensity to spread their research activities across increasing numbers of technological fields, meaning there is a positive relationship between country size and technological diversification (Archibugi et al., 1992). This subsection thus is motivated to test this hypothesis in the Chinese context. However, in previous studies many scholars took only a country's technology size (measured through the number of patent applications) as the size proxy. As Cantwell and Vertova (2004) point out, a country can be large in terms of population or natural resources but be small in terms of technological development, citing China and India as having large populations but during their earlier period of measurement, being technologically small. To test the hypothesis robustly we employ three measures, the technology size (i.e. total patent applications), the population, and the gross domestic production (GDP) as different measures of size. All these three size indicators are taken in logarithmic form. These results are shown in figures 4, 5, and 6.

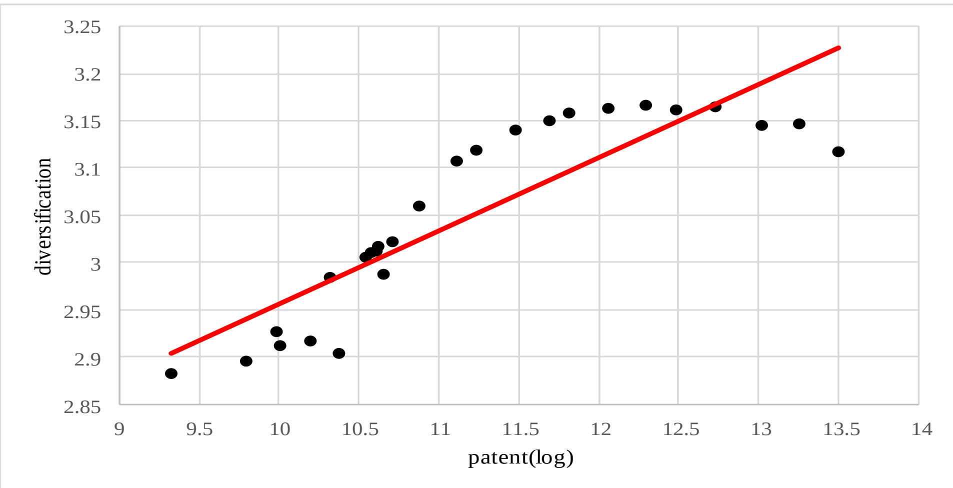

Fig.4. Technological diversification against patent applications

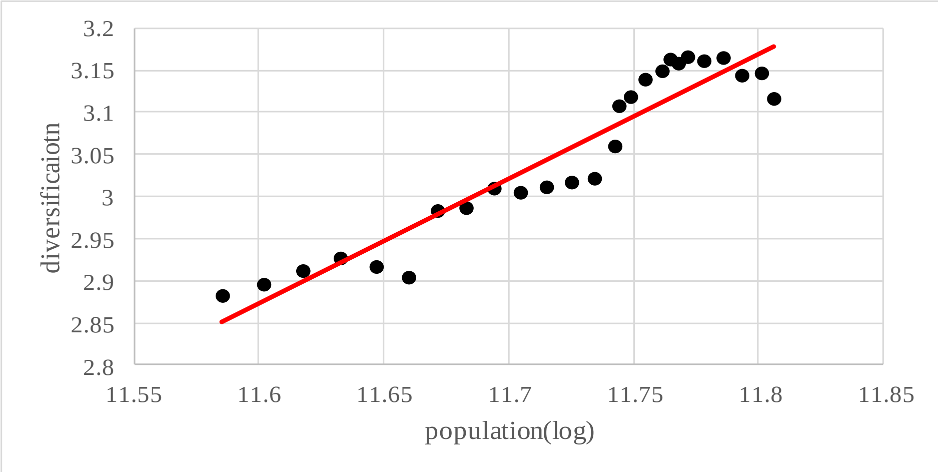

Fig.5. Technological diversification against population

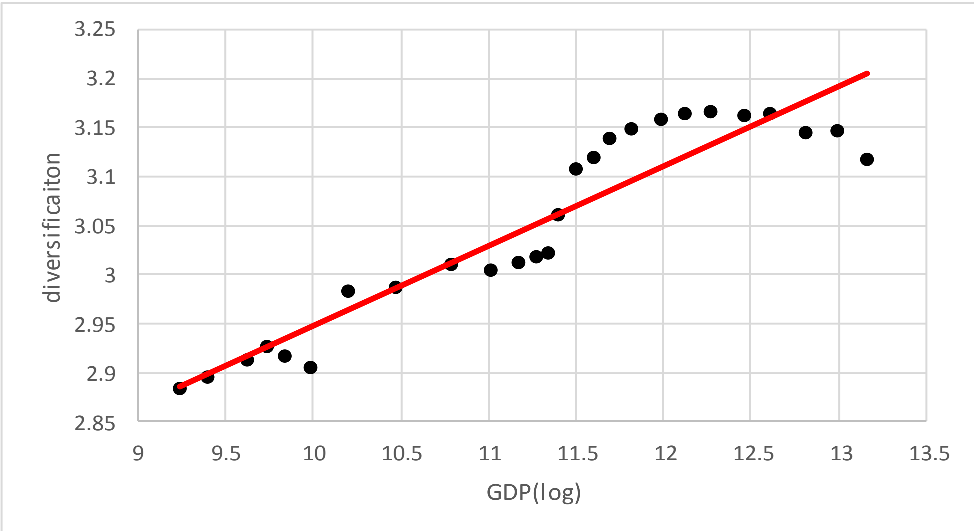

Fig.6. Technological diversification against GDP

Figures 4, 5, and 6 uniformly show that technological diversification increases when the size becomes larger however measured, by total number of patent applications, population, and GDP. This finding confirms the size-diversification relationship for China, as found in the earlier studies for developed countries. To examine the hypothesis at the regional level in greater depth, instead of using the time-series data over 1986-2011, we took a snapshot of four years within the sample, and used cross-sectional data from the 30 Chinese provinces[2] in each year (1986, 1990, 2000, and 2011) to draw the relationship between province/regional technological diversification and total province patent application (taken in logarithmic form). The result is presented in Figure 7. Figure 7 also supports the size-diversification hypothesis although in more muted form, with a more shallow slope in the relationship. For all the chosen typical years - 1986, 1990, 2000 and 2011 - the linear relationship is evident. Moreover the slope in 2011 has decreased compared with previous years, but a linear effect is still observed.

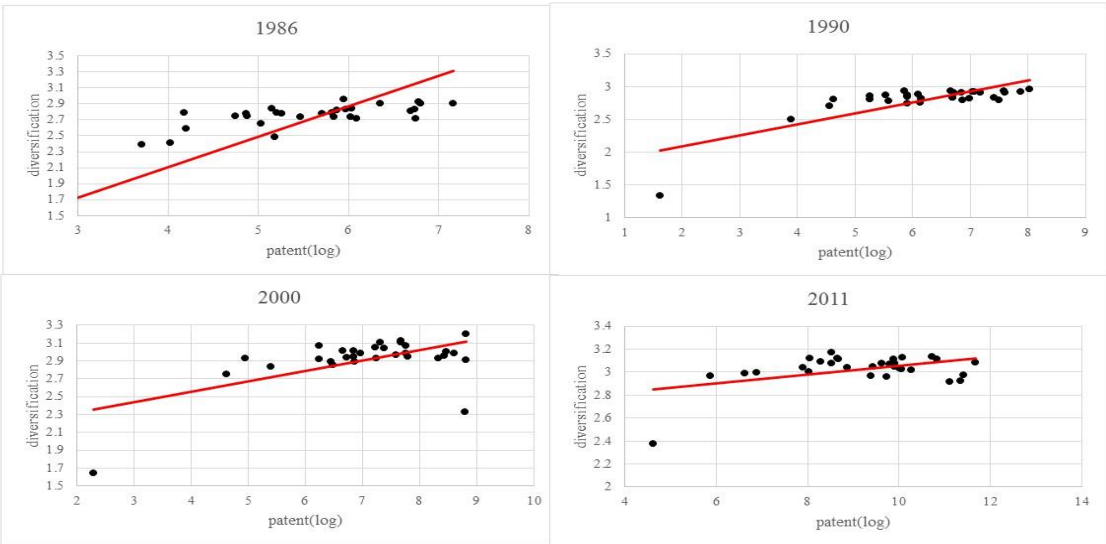

Fig.7. Province technological diversification against patent applications in typical years

Shifts in size-diversification relationship

It is apparent from Figure 7 that the slope of the relationship changes over

[2] In this study, thirty administrative provincial-level regions were selected as the analysis unit. Here an administrative unit is a province, a municipality or an autonomous region in China. Since Hong Kong, Macao, Taiwan and Tibet are different in their economic conditions from most of the other regions in the mainland and also information from these regions is not easily available, this paper excludes them from the analysis and thus only thirty regions were included. In the following, we will refer to the administrative units as regions and do not make distinctions between provinces, municipalities, and autonomous regions.

time, progressively flattening out. We explore this further.

In this section we decompose the size-diversification relationship into the amount attributable to an increase in size and an amount attributable to structural shift in the diversification parameter. We wish to separate out the effects of extensive growth in size from the effects of movement across technological fields.

We use a bivariate regression model to investigate the size-diversification relationship at the level of province technological diversification. We use a panel of data including the 30 provinces and 5, 11, and 12 years of continuous observations in each period. In this way we are able to generate enough observations to test a model of technological diversification of the following form.

$$diversification_{it} = \alpha + \beta$$

We can distinguish two different effects: (1) the size effect, represented by movements along the regression line. If the regression line is fixed from one historical period to the next, then all changes in the extent of diversification are essentially a function of a change in the provinces' technological size or, in other words, in growth in the number of patents (2) the structural shift effect, represented by movements of the regression line. If the regression line shifts from one historical period to the next, then determinants other than size (i.e., changes in the economic and institutional context) need to be taken into account.

Figure 8 exhibits the three regression lines found within each historical period and table 4 illustrates the separate effects of changes in the size-diversification relationship due to changes in technological size and due to the structural shift effect. In table 4, we control the effect of rising technological size in the first step, then we identify the structural shift effect. In line with prior publications (e.g. Cantwell et al., 2004), we calculate the size and structural shift effects following certain steps:

- Columns (1) and (2) are the average of log(size) and technological diversification from the original data;
- Columns (3) and (4) are the difference of log (size) and technological diversification from one period to the next calculated from the original data;
- Column (5) is the estimate of the dependent variable (technological diversification), imputed from the regression of the prior period and so owing entirely to the effect of size assuming that the structural relationship has remained unchanged.
- Column (6) presents the notional change in technological diversification owing to the size effect, calculated by the difference between the estimated average technological diversification (column 5) and the actual average technological diversification (column 2) of the prior period;
- Column (7) represents the change in technological diversification

owing to the structural shift effect, which is the difference between column (4), the total actual change in technological diversification, and column(6), the estimated change in technological diversification that is attributable to the size effect.

Thus, Columns (6) and (7) offer the measure of the two different effects associated with a change over time in the size-diversification relationship, namely the size-effect and the structural shift effect. Combining the graphical results in figure 8 with tabular calculation of the statistical decompositions in table 4, we find that the changes in the size-diversification relationship in China between historical periods were dominated by the structural effects, between historical periods. Thus there were positive structural shift effects signifying greater specialization counteracted by a slightly negative size effects (+0.13 shift effect and -0.03 size effect in the rapid marketization period and +0.18 shift and -0.04 size effects in the globalization period). Figure 8 presents this flattening of the size-diversification relationship over time, attributable entirely to the structural shift effects of specialization. This translates into a gradual process of technological specialization that has been occurring right through China's development periods alongside the positive relationship between size and technological diversification.

How does this differ from the earlier processes of diversification and specialization observed for developed countries? In their cross-country study Cantwell and Vertova (2004) found that the size-diversification relationship changed both in the same direction: both increasing in slope (where there has been a flattening of slope for China) and increasing diversification in the first three periods. So increasing size and structural shift effects of diversification complemented each other in the developed countries' development trajectories. This relationship in the developed countries then reversed direction with a very marked increase in technological specialization in their most recent period 1965-90 of internationalization. They attributed this most recent shift to the then new phase of internationalization and technological integration of multinationals in host countries that led to their specialization by country in the technologies that that particular country was strongest in.

China has entered this process of technological development when the developed countries were already in their internationalization phase. China appears to have leapt straight into the process of more gradual and continuous shifting in favour of technological specialization with the slope of the size-diversification line becoming flatter over time. This could be interpreted as China becoming integrated right from its marketization phase into that process of technological integration and specialization identified by Cantwell and Vertova. We can see this in part in the form of the inward foreign R&D investments by multinationals which took off in the 1990s, with the aim of making use of cheaper scientists and engineers in China to accomplish relatively simple tasks (Asakawa & Som, 2008; Gassmann & Han, 2004). This might be contributing to this shift towards specialization.

This suggests probing further to understand the underlying causes of this tendency towards technological specialization alongside an increase in diversification attributable to extensive growth in patenting. We present several prominent characteristics of the Chinese national innovation system that may have affected this structural change in the size-diversification relationship over time from the first to the third historical period. (see Table 5).

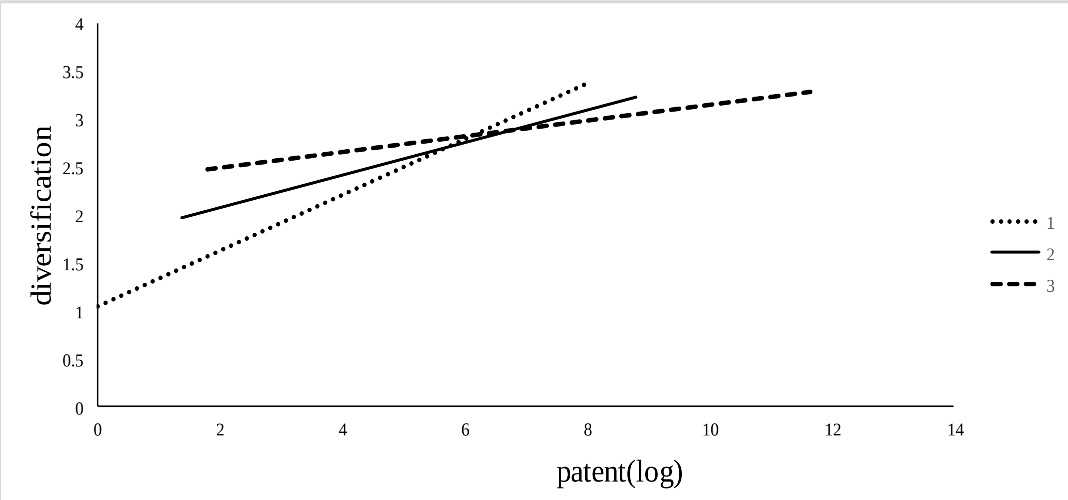

Fig.8. The size-diversification relationship over time. Notes: (1) indicates the regression line in the pre-marketization period, (2) indicates the regress line in the rapid-marketization period, (3) indicates the regression line in the globalization period.

Table 4 The size effect and the structural shift effect

	Average log(size)(1)	Average technological diversification(TD)(2)	Change in log(size)(3)	Change in TD(4)	Estimated average TD(5)	Notional due to size effect(6)	Change due to structural shift effect(7)
Pre-marketization(1986-1990)	5.6654	2.9071					

Rapid-marketization(1991-2000)	6.6656	3.0110	1.0002	0.1039	2.9814	-0.0296	0.1335
Globalization(2001-2011)	8.0822	3.1484	1.4166	0.1374	3.1072	-0.0412	0.1786

First, from the late 1990s through to the early 21st century China experienced a rapid increase in R&D and innovation activities. R&D investments increased nearly 10 fold from the rapid-marketization period to the globalization period. Alongside this growth in R&D there has been a structural shift in the form that that R&D has taken. Firms have become major players of R&D activities in the globalization period, replacing public organizations which played the most prominent role in R&D in the pre-marketization period (Sun and Liu 2010). For example, government-controlled universities and research institutes used to account for the bulk of R&D, which has given way to enterprises' much greater role in R&D activities in the more recent periods. This structural change in R&D investments followed the shift from the era of the planned economy when most R&D activities were done for military and key projects in public organizations to the marketization era when industry has played an increasingly prominent role (Liu & White, 2001). This has led to an extension in China's technology profile including a proliferation of technology fields, particularly in civil sectors. We consider this as the first factor resulting in the structural shift effect in the relationship of size-diversification.

Second, for Cantwell and Vertova (2004), they saw inward foreign R&D investments as the driver of a country's shift of size-diversification towards more specialization. For China we believe that as well as foreign investment into R&D increasing specialization, the effect of general investments targeting China's growing domestic markets and lowering manufacturing cost have also contributed to the structural shift in China's technology profile. The growing diversity of demand for both domestic and export goods in China are reflected in the change in technology profile with more diversified R&D activities and innovations (Altenburg et al., 2008; Cheung & Lin, 2004; Ganotakis & Love, 2011). This argument is supported by the dramatic increase of inward foreign investment, international trade, and GDP (see table 5).

Third, we suggest that the growing role of local governments, replacing central government in the national innovation system has also contributed to the shift of the relationship between size and diversification in China (Liu, Simon, Sun, Cao 2011). With a deepening in Chinese reform and decentralization combined with the policy of opening out the regional economy to trade and investment in the 1990s and 2000s, local governments have been stimulated to develop technologies more suited to their local economic and social needs (Chang & Shih, 2004). As a result, technological development became more localized and more specialized to that province or region. Chinese central government has remained in charge of major funding for military, public health and security and newly emerging and strategic technologies but has left local governments to develop according to their own strategic needs. This is likely to have contributed to a more regionally specialized technological profile across the Chinese regions, and contributed towards both a more diversified profile at the country level and to the structural shift towards specialization in the size-diversification relationship. In the last column in Table 5, it is observed that the ratio of local government expenditure out of national spending increased from 61% to 71% over the three periods, reflecting this increasing regional expansion and specialization.

Table 5 The structural change of China profile in technology evolution

	Expenditure on R&D (100 million yuan)	Ratio of corporation R&D expenditure (%)	International trade (USD 100million)	Amount of foreign investment(USD 100million)	GDP (100 million yuan)	Ratio of local government expenditure (%)
Pre-marketization （1986-1990）						
（1986-1990）	327.24(1988-1990)	41.12	4864.11	146.31	73036.71	61.01
Rapid-marketization （1991-2000）						
（1991-1995）	1043.63	39.76	10144.10	1441.76	193030.51	69.74
（1996-2000）	3039.61	48.66	17739.10	2134.81	423443.61	70.08
Globalization （2001-2011）						
（2001-2005）	8285.97	63.81	45578.68	2861.62	710626.41	71.02
（2006-2011）	32880.99	70.15	153207.75	6821.86	2011157.10	71.41

Note: R&D expenditure during 1986-1990 is assembled from 1988 to 1990 due to data before 1988 is unavailable.

Conclusion and discussion

This study is motivated to compare the technological diversification profile over time of China over the last 25 year period from 1986-2011 with the earlier studies of technological diversification for earlier trajectories of development from 1890-1990 followed by now developed countries. Literature on technological diversification whether at the country or firm level has been focused on the developed countries, accounting for well over 90% of all patenting activity during the period studied. This paper wishes to understand whether the technological development trajectory of China has been following a similar pattern.

This study is at the country-level for China, based on 3.7 million patents at the macro-level. We have three key findings: we chart the historical evolving trend in technological diversification at both national and provincial/regional levels; we re-examine the size-diversification hypothesis in the context of China at country and regional levels; and we decompose the size-diversification relationship into that part attributable to size and that part owing to structural changes in diversification.

Our study shows that there was an increased trend in diversification over time in China which peaked in 2006; this is in line with the observed trend in developed countries that rose for the initial extensive phases of development and then declined. This study uses several measures of size to test the size-diversification hypothesis: total patent applications, population, and GDP as proxies for size. All of these measures are positively correlated with technological diversification. In order to make this hypothesis more robust, we also used cross-provincial data, and chose four points scattered along our observation period, to re-examine the size-diversification hypothesis. This is supportive of the hypothesis too. Thus, we confirm that the size-diversification hypothesis is applicable in China.,

We also observed a structural shift towards specialization within the size-diversification relationship in China over the three historical periods, the pre-marketization period (1986-1990), the rapid marketization period (1991-2000), and the globalization period (2001-2011). To understand the reasons for this shift, we used a decomposing method to distinguish two different effects, the size effect, and the structural shift effect. Based on this method, we found that structural shift effects dominated the size-diversification effects and moved towards specialization from the outset of the development/marketization process. This contrasts with the studies for developed countries where early structural shifts moved in favour of technological diversification and complemented increases in technological size. In the internationalization phase of development (1965-90) this technological diversification was reversed turning into greater technological specialization. Cantwell and Vertova (2004) argued that this was due to the internationalization of multinationals in host countries and their specialization towards their host countries' particular strengths.

This study for China proposes three key factors as the driving forces behind the shift towards specialization in the Chinese size-diversification relationship: the increased scale of R&D investment and structural change and more specialized nature of institutions making those investments; the growing integration into the specialized global R&D community albeit at a fairly primitive stage; and the rise of local governments' responsibility for R&D activities giving rise to greater regional specialization. These explanations are based on various sources of evidence.

Finally we would argue that although these findings are applicable to China as a transitioning country, we are not sure whether these findings are applicable to other smaller developing countries. In particular, just as the size of the US economy in the earlier technological development trajectory led to its being an outlier in terms of pushing the structural shifts in the size-diversification relationship observed in earlier studies, so China's size and weight amongst developing countries particularly in relation to R&D, might well be driving those relationships in a Chinese direction which is not applicable to smaller economies on a more specialized technological trajectory from the outset.

References

Altenburg, T., Schmitz, H., & Stamm, A. 2008. Breakthrough China's and India's transition from production to innovation. ***World Development***, 36(2): 325-344.

Archibugi, D., & Pianta, M. 1992. Specialization and size of technological activities in industrial countries: The analysis of patent data. ***Research Policy***, 21(1): 79-93.

Archibugi, D., & Planta, M. 1996. Measuring technological change through patents and innovation surveys. ***Technovation***, 16(9): 451-468.

Asakawa, K., & Som, A. 2008. Internationalization of R&D in China and India: Conventional wisdom versus reality. ***Asia Pacific Journal of Management***, 25(3): 375-394.

Bell, M., & Pavitt, K. 1993. Technological Accumulation and Industrial Growth: Contrasts Between Developed and Developing Countries. ***Industrial & Corporate Change***, 2(2): 157-210.

Breschi, S., Lissoni, F., & Malerba, F. 2003. Knowledge-relatedness in firm technological diversification. ***Research Policy***, 32(1): 69-87.

Cantwell, J., & Vertova, G. 2004. Historical evolution of technological diversification. ***Research Policy***, 33(3): 511-529.

Cesaroni, F. 1997. Technological diversification, technology strategies and licensing in the chemical processing industry. ***ROUTLEDGE STUDIES IN THE MODERN WORLD ECONOMY; 34 2004***: 176-202.

Chang, P.-L., & Shih, H.-Y. 2004. The innovation systems of Taiwan and China: a comparative analysis. ***Technovation***, 24(7): 529-539.

Chen, J. H., Jang, S.-L., & Wen, S. H. 2010. Measuring technological diversification: Identifying the effects of patent scale and patent scope. ***Scientometrics***, 84(1): 265-275.

Chen, Y.-S., & Chang, K.-C. 2012a. Using the entropy-based patent measure to explore the influences of related and unrelated technological diversification upon technological competences and firm performance. ***Scientometrics***, 90(3): 825-841.

Chen, Y.-S., Shih, C.-Y., & Chang, C.-H. 2012b. The effects of related and unrelated technological diversification on innovation performance and corporate growth in the Taiwan's semiconductor industry. ***Scientometrics***, 92(1): 117-134.

Cheung, K.-y., & Lin, P. 2004. Spillover effects of FDI on innovation in China: Evidence from the provincial data. ***China Economic Review***, 15(1): 25-44.

Chiu, Y.-C., Lai, H.-C., Liaw, Y.-C., & Lee, T.-Y. 2010. Technological scope: diversified or specialized. ***Scientometrics***, 82(1): 37-58.

Gambardella, A., & Torrisi, S. 1998. Does technological convergence imply convergence in markets? Evidence from the electronics industry. ***Research Policy***, 27(5): 445-463.

Ganotakis, P., & Love, J. H. 2011. R&D, product innovation, and exporting: Evidence from UK new technology based firms. ***Oxford Economic Papers***, 63(2).

Garcia-Vega, M. 2006. Does technological diversification promote innovation?: An empirical analysis for European firms. ***Research Policy***, 35(2): 230-246.

Gassmann, O., & Han, Z. 2004. Motivations and barriers of foreign R&D activities in China. ***R&D Management***, 34(4): 423-437.

Gort, M. 1962. ***Diversification and Integration in American Industry***. Princeton,NJ: Princeton University Press.

Granstrand, O., & Sjolander, S. 1990. Managing innovation in multi-technology corporations. ***Research Policy***, 19(1): 35-60.

Hagedoorn, J., & Cloodt, M. 2003. Measuring innovative performance: is there an advantage in using multiple indicators? ***Research Policy***, 32(8): 1365-1379.

Hausman, J. A., & Griliches, Z. 1984. Econometric models for count data with an application to the patents-R&D relationship. ***Economic and Political Weekly***, 27: 909-938.

Hong, W., & Su, Y.-S. 2013. The effect of institutional proximity in non-local university-industry collaborations: An analysis based on Chinese patent data. ***Research Policy***, 42(2): 454-464.

Kim, D.-J., & Kogut, B. 1996. Technological Platforms and Diversification. ***Organization Science***, 7(3).

Kim, H., Lim, H., & Park, Y. 2009. How should firms carry out technological diversification to improve their performance? An analysis of patenting of Korean firms. ***Economics of Innovation & New Technology***, 18(8:99-116).

Laursen, K. 1996. Horizontal diversification in the Danish national system of innovation: the case of pharmaceuticals. ***Research Policy***, 25(7): 1121-1137.

Leten, B., Belderbos, R., & Van Looy, B. 2007. Technological diversification, coherence, and performance of firms. ***Journal of Product Innovation Management***, 24(6): 567-579.

Li, X. 2009. China's regional innovation capacity in transition: An empirical approach. ***Research Policy***, 38(2): 338-357.

Liu, X., & White, S. 2001. Comparing innovation systems: A framework and application to China's transitional context. ***Research Policy***, 30(7): 1091-1114.

Luan, C., Liu, Z., & Wang, X. 2013. Divergence and convergence: technology-relatedness evolution in solar energy industry. ***Scientometrics***, 1(1): 1-10.

Miller, D. J. 2006. Technological diversity, related diversification, and firm performance. ***Strategic Management Journal***, 27(7): 601-619.

Nachum, L. 1999. Diversification strategies of developing country firms. ***Journal of International Management***(5): 115-140.

Patel, P., & Pavitt, K. 1997. The technological competencies of the world's largest firms: Complex and path-dependent, but not. ***Research Policy***, 26(2): 141-156.

Piscitello, L. 2000. Relatedness and coherence in technological and product diversification of the world's largest firms. ***Structural Change and Economic Dynamics***, 11(3): 295-315.

Purkayastha, S., Manolova, T. S., & Edelman, L. F. 2012. Diversification and performance in developed and emerging market contexts: A review of the literature. ***International Journal of Management Reviews***, 14(1): 18-38.

Rumelt, R. P. 1974. ***Strategy, Structure, and Economic Performance, Divisiofi of Research***. Boston: Harvard Business School.

Sun, Y. 2000. Spatial Distribution of Patents in China. ***Regional Studies***, 34(5): 441-454.

Watanabe, C., Hur, J. Y., & Matsumoto, K. 2005. Technological diversification and firm's techno-economic structure: An assessment of Canon's sustainable growth trajectory. ***Technological Forecasting and Social Change***, 72(1): 11-27.

Zander, I. 1997. Technological diversification in the multinational corporation—historical evolution and future prospects. ***Research Policy***, 26(2): 209-227.

Appendix: Technological categorization and relevant patent classification

Technological Field	Patent Classification
Electrical Devices and Engineering	F21,G05F,H01B,H01C,H01F,H01G,H01H,H01J,H01K,H01M,H01R,H01T, H02,H05B,H05C,H05F,H05K
Audio-visual Technology	G09F,G09G,G11B,H03F,H03G,H03J,H04N,H04R,H04S

Communication	G08C,H01P,H01Q,H03B,H03C,H03D,H03H,H03K,H03L,H03M,H04B,H04H,H04J,H04K,H04L,H04M,H04Q
Information Technology	G06,G10L,G11C
Semiconductor	B81,H01L
Optics	G02,G03,H01S
Control and Instrumentation Technology	G01B,G01C,G01D,G01F,G01G,G01H,G01J,G01K,G01L,G01M,G01N,G01P,G01R,G01S,G01V,G01W,G04,G05B,G05D,G07,G08B,G08G,G09B,G09C,G09D,G12
Medical Technology	A61B,A61C,A61D,A61F,A61G,A61H,A61J,A61L,A61M,A61N
Nuclear Engineering	G01T,G21,H05G,H05H
Fine Organic Chemistry	C07C,C07D,C07F,C07G,C07H,C07J
Polymer Chemistry	C08B, C08F,C08G,C08H,C08K,C08L,C09D,C09J
Chemical Engineering	B01,B02C,B03,B04,B05B,B06,B07,B08,F25J,F26B
Surface Processing, Coating	B05C,B05D,B32,C23,C25,C30
Material, Metallurgy	B22,B82,C01,C03C,C04,C21,C22
Biotechnology	C07K,C12M,C12N,C12P,C12Q,C12S
Pharmaceuticals, Cosmetics	A61K,A61P
Agriculture, Food	A01H,A21D,A23B,A23C,A23D,A23F,A23G,A23J,A23K,A23L,C12C,C12F,C12G,C12H,C12J,C13D,C13F,C13J,C13K
Petroleum Industry & Material Chemistry	A01N,C05,C07B,C08C,C09B,C09C,C09F,C09G,C09H,C09K,C10,C11
Hauling & Printing	B25J,B41,B65,B66,B67B,B67C,B67D
Food Processing, Machinery and Equipment	A01B,A01C,A01D,A01F,A01G,A01J,A01K,A01L,A01M,A21B,A21C,A22,A23N,A23P,B02B,C12L,C13C,C13G,C13H
Material Processing, Textile, Papermaking	A41H,A43D,A46D,B28,B29,B31,C03B,C08J,C14,D01,D02,D03,D04B,D04C,D04G,D04H,D05,D06(except F、N),D21
Environmental Technology	A62D,B09,C02,F01N,F23G,F23J
Machine Tool	B21,B23,B24,B26D,B26F,B27,B30
Engine, Pump, Turbine	F01B,F01C,F01D,F01K,F01L,F01M,F01P,F02,F03,F04,F23R
Heat Treatment and Equipment	F22,F23B,F23C,F23D,F23H,F23K,F23L,F23M,F23N,F23Q,F24,F25B,F25C,F27,F28
Mechanical Components	F15,F16,F17,G05G
Transportation	B60,B61,B62,B63B,B63C,B63H,B63J,B64B,B64C,B64D,B64F
Space Technology and Weapon	B63G,B64G,C06,F41,F42
Consumer Goods and Equipment	A24,A41B,A41C,A41D,A41F,A41G,A42,A43B,A43C,A44,A45,A46B,A47,A62,A63,B25B,B25C,B25D,B25F,B25G,B25H,B26B,B42,B43,B44,B68,D04D,D06F,D06N,D07,F25D,G10B,G10C,G10D,G10F,G10G,G10H,G10K
Civil Engineering, Mining, Architecture	E01,E02,E03,E04,E05,E06,E21