Paper to be presented at the

DRUID Society Conference 2014, CBS, Copenhagen, June 16-18

Funding for some, spills for others: Explaining the emergence of nanotechnology in Chinese regions

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Abstract

By acquiring the capabilities to lead in the development of emerging technology systems, less developed countries can rapidly hasten the process of their technological catching up or forging ahead. In this context, nanotechnology represents a set of science-based enabling technologies that are still in the early stages of their technological life cycles and that promise significant long-term pay offs to countries pioneering their development and commercialization. This paper investigates the factors driving nanotechnology development in Chinese regions. Although advanced regions of China spearheaded the country?s rapid growth in nanotechnology, other regions are increasingly involved in the development of this technology. Results from a dynamic panel data analysis suggest that distinctive factors drive nanotechnology development in regions with different levels of scientific capability. On the one hand, in regions with superior scientific capabilities, governmental financing exerted a major impact on the growth of nanotechnology. In lagging regions, on the other hand, it was not governmental support but the spillovers of knowledge from other regions through the collaboration network of scientists that contributed to the development of this technology.

Jelcodes:O31,O32

Funding for some, spills for others:

Explaining the emergence of nanotechnology in Chinese regions

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Abstract

By acquiring the capabilities to lead in the development of emerging technology systems, less developed countries can rapidly hasten the process of their technological catching up or forging ahead. In this context, nanotechnology represents a set of science-based enabling technologies that are still in the early stages of their technological life cycles and that promise significant long-term pay offs to countries pioneering their development and commercialization. This paper investigates the factors driving nanotechnology development in Chinese regions. Although advanced regions of China spearheaded the country's rapid growth in nanotechnology, other regions are increasingly involved in the development of this technology. Results from a dynamic panel data analysis suggest that distinctive factors drive nanotechnology development in regions with different levels of scientific capability. On the one hand, in regions with superior scientific capabilities, governmental financing exerted a major impact on the growth of nanotechnology. In lagging regions, on the other hand, it was not governmental support but the spillovers of knowledge from other regions through the collaboration network of scientists that contributed to the development of this technology.

1. Introduction and background

For less developed countries, who typically occupy follower positions in mature technologies that have long lost their dynamism, a ‘real’ catching-up process requires acquiring the capability to develop a new technology system (Perez and Soete 1988). Such a system provides enormous opportunities for successive improvements across a range of technologies that can generate economy-wide technological externalities lasting several decades. An early entry into a new technology system therefore can trigger faster catching up and long run success.

In this respect, nanotechnology represents a set of science-based enabling technologies that are still in the early stages of their technological life cycles and that promise significant long-term pay offs to countries engaging in their development and commercialization. Studies have shown that nanotechnology can serve as a general purpose technology that has applications across a broad spectrum of economic activities spanning almost all fields of manufacturing (Shapira and Youtie, 2008; Wang et. al. 2013). In other words, countries that occupy frontier positions in nanotechnology are likely to lead in many fields of innovation in the years to come.

Large less developed countries with a strong scientific-research tradition, such as China, have been expected to provide global leadership in emerging science-based technologies such as biotechnology and nanotechnology (Niosi and Reid, 2007). In this respect, over the last decade or so, as China began undergoing its transformation from an investment-driven to an innovation-driven economy, the country experienced dramatic progress in the development of nanotechnology. The scientific output in nanotechnology from China, as measured by nanotechnology-related publications with a Chinese address, has been increasing exponentially. Whereas in 2000 the number of nanotechnology-related publications from China stood at a paltry 30% of the US level, by 2010 it rose to 92%[1]. The same period also witnessed a remarkable increase in the number of annual nanotechnology-related patent applications filed locally, from 275 to 6,333.

Financial support from the state is generally viewed as a vital ingredient to the emergence of a new technology system. Private sector investment in such a system, especially in the early stages, will be less than optimum because of the high levels of uncertainty about not just the technological outcomes but also the commercial

[1] Data source is UNU-MERIT nano-database.

potentials of the newly-developed technologies. In China, nanoscience and nanotechnology drew favourable policy interest already in the 1980s when these concepts first emerged. However, it was not until 1990 that serious efforts to promote nanotechnology began, with the Ministry of Science and Technology launching the ten-year “Climbing-Up” project (Bai 2001, Tang, Wang & Shapira 2010). Soon after, the concept began trickling through the scientific ranks and the Chinese Academy of Sciences (CAS), the National Natural Science Foundation of China (NSFC), and the State Science and Technology Commission (SSTC) began funding nanoscience-related work and activities (Chunli Bai, 2005). Today, according to the China Association for Science and Technology, the three most widely used high-tech words in China are “computer”, “gene” and “nanometer”.

In this paper, we examine the growth of nanotechnology in China with a particular focus on whether the dynamics of this growth vary across Chinese regions with different scientific capabilities. We argue that the large-scale governmental aid for nanotechnology development would have made a notable impact only in regions possessing high scientific capabilities. Regions lagging behind in scientific capabilities would not have the necessary complementary resources either to be major beneficiaries of government support in the first place or to make an efficient use of the support received from the state. However, we suggest, drawing on the economic geography literature, that lagging Chinese regions can leverage their scientists’ formal collaboration links to bring in spillovers of nanotechnology from other regions. The collaboration network of scientists acts as an important resource for lagging regions, partly compensating for their weak scientific capabilities. Our focus on the differential sources of nanotechnology development contributes to the economic geography literature on knowledge spillovers and to the catch up literature that stresses the development of a new technology system for faster catching up.

The paper is organized as follows. The following section provides a theoretical and empirical background to the study and raises the specific questions for empirical scrutiny. The third section presents the data and explains the methods. The results of the empirical analysis are discussed in the fourth section, and the final section concludes.

2. Background and research questions

2.1 A technology system perspective of nanotechnology, and nanotechnology's emergence in China

Both the traditional catch up literature (e.g. Gerschenkron, 1962) and the new-growth theories (Grossman and Helpman 1991; Rivera-Batiz and Romer 1991) stress the role of international technology diffusion for the catching up of less developed countries to the income levels of developed countries. In both these perspectives, mature technologies developed in advanced countries represent a major opportunity that less developed countries might exploit so they can avoid the costly, time consuming, and challenging task of developing new technologies from scratch. However, another perspective, whose spirit we embrace in this paper, emphasizes the importance of less developed countries taking a leadership role in the development of a new technology system (Perez and Soete 1988). In this view, a new technology system impacts growth in a broad range of sectors and generates economy-wide knowledge spillovers, thereby accelerating the catching-up process. Well-known examples of this process are South Korea and Taiwan which focused early on in developing the electronics industry, at a time when this industry was fast emerging and when both countries had little prior experience in this or related industries. In this context, given that nanotechnology has applications in a wide spectrum of activities, a leadership position in nanotechnology implies a significant 'window of opportunity' for a large less developed country like China to accelerate its catch up to the global techno-economic frontier.

In developing a science-based technology like nanotechnology, less developed countries are not particularly at a comparative disadvantage vis-a-vis developed countries. This because many in the former category of countries, and in particular China, have universities and research institutes that boast of a rich heritage in scientific research. Realizing the tremendous potential of nanotechnology, China has been adopting an ambitious nanotechnology development strategy. Key to this has been the extensive financing for nanotechnology research under the National Natural Science Foundation program. Following the substantial progress made by China in information and communication technologies over the past decades (Lazonick and Li, 2012; Lazonick, 2004; Lu, 2000), the government's efforts to promote nanotechnology are aimed at setting off another technological wave in China.

2.2 The geography of knowledge development

It is widely acknowledged that technological activities tend to be unevenly distributed across regions (or countries), with high-technology activities in particular concentrated in geographic clusters (Verspagen and Schoenmakers, 2004; Henderson, 2003; Niosi, 2001; Antonelli, 2001; Niosi and Queenton, 2010). In China, given the wide regional inequality in scientific capabilities, the emergence of nanotechnology unavoidably started in a few leading regions. Few studies have explored the question of the extent to which other regions are involving in nanotechnology development. Motoyama, et al. (2014) was one of the first attempts to address the question of regional convergence or divergence of nanotechnology development in China. They, adopting a spatial correlation technique, found very little diffusion of knowledge and predicted that the divergence trend would continue. However, we argue that for a fuller understanding of regional dimensions of knowledge development in a large country like China, it is important to go beyond the traditional spatial proximity framework and take into account knowledge flows through the collaboration network of scientists. This is because, as we discuss below conceptually and in section 4.2 empirically in the Chinese context, diffusion of knowledge from other regions can compensate for the initially weak innovation systems of less developed regions.

2.3 Channels of knowledge flows

There is a vast literature that examines spillovers of knowledge across regions, nations, firms or industries (for reviews see, Frenken et al. 2010; Wang et al. 2013; Jacob & Meister, 2005). A dominant strand of this literature emphasizes that knowledge externalities occur locally, rather than globally (Jaffe 1989; Antonelli 2001; Abramovsky and Simpson, 2008; Arundel and Guena, 2004). The localized character of knowledge spillovers, the argument goes, stems from the tacit nature of knowledge. This renders the acquisition of knowledge simply from technology blueprints difficult, and therefore calls for close, often informal, people to people interaction. A few authors, however, are more explicit about the specific mechanism of knowledge flows, arguing that it may not necessarily be the ‘knowledge in the air’, but the locally-bound scientific networks that generate localized knowledge flows (Zucker, et al, 1998; Breschi & Lissoni 2009).

However, there is increasing evidence that geographic distance is not a limiting factor for knowledge spillovers. Formal linkages, such as co-authorship ties, can facilitate knowledge flows over long distances (Cockburn and Henderson, 1997; Ponds et al, 2009). These linkages provide an important means for regions or countries to tap into the resources and knowledge of more advanced regions or countries. Several studies have documented the fast growth of collaboration in science, with some highlighting that international collaborations generate higher quality research (higher citation rates) than domestic collaborations (Frenken et al. 2010; Tang and Shapira, 2011), or facilitate entry into new research fields (Tang and Shapira, 2011).

2.4 Empirical framework and Research questions

Drawing on the preceding discussion, we propose an empirical framework for understanding the development of nanotechnology in Chinese regions. Two factors are integral to explaining the growth in nanotechnology across Chinese regions in our framework: the sizeable governmental financial support and inter-regional and international knowledge spillovers. We focus on collaboration networks as the main conduits for knowledge spillovers, while also taking on board the effect of geographic proximity between regions. Given that collaboration networks evolve over time, we treat collaboration as a dynamic construct; existing literature has paid only scant attention to the dynamic aspect of collaboration due primarily to the use of cross sectional data.

A particular novelty of our study is that we carryout separate analysis for leading and lagging regions in scientific capabilities. The dynamics of knowledge development in these two sets of regions are likely to be different. Even if advanced and lagging regions received the same level of funding, they would likely generate differential returns just because advanced regions can leverage their superior capabilities to generate greater *bang for the buck* compared to lagging regions wherein funds would be less efficiently utilized. Nevertheless, lagging regions can benefit from collaborations between their scientists and those from advanced regions. The benefits for advanced regions through these collaborations are likely minimal (aside from the goodwill they have gained).

The following are the specific question we explore in this paper.

- To what extent has funding for nano technology research by the Chinese government succeeded in stimulating development of nanotechnology in Chinese regions?
- To what extent have collaboration networks and geographic proximity generated inter-regional spillovers of nano technology knowledge in general, and funding-induced knowledge spillovers in particular?
- Do differences in the scientific and technological capabilities of regions affect the extent to which regions benefit from state funding and from knowledge

spillovers? Specifically, do lagging regions benefit more from regional spillovers than from state funding, and vice versa?

3. Data and variables

For the econometric analysis, we use a panel data set of 30 Chinese regions[2] spanning 11 years (2000-2010). The dependent variable is patent applications filed from a Chinese region at China's State Intellectual Property Office (SIPO), capturing the region's technological output. We employ over 30,000 nano patent applications gathered from the China Patents Full-text Database.

The key independent variables are nano funding that a region received from the National Natural Science Foundation; inter-regional spillovers; and international spillovers. Inter-regional spillovers in our framework stem from two sources: one is the patents of a region, and the other is the nano funding received by a region. We identify two carriers of spillovers: the region-spanning collaboration network of scientists and the geographic proximity between regions. The first of these carriers is defined in terms of a dynamic collaboration matrix as follows:

$$\begin{bmatrix} P_{1,1,t} & P_{1,2,t} & \cdots & \cdots & \cdots & P_{1,31,t} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ P_{i,1,t} & \cdots & \cdots & P_{i,j,t} & \cdots & \vdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ P_{31,1,t} & \cdots & \cdots & \cdots & \cdots & P_{31,31,t} \end{bmatrix}$$

In the matrix, an element P_{ijt} is the number of co-authored nano publications involving the regions *i* and *j* in year *t*. The spillovers from patented technologies ($\text{TECHSPILL}_{\text{ijt}}$) and nano funding ($\text{FUNDSPILL}_{\text{ijt}}$) that region *i* receives from region *j* are defined respectively as:

$$\text{TECHSPILL}_{\text{it}} = \frac{\text{PUB}_{ijt}}{\text{PUB}_{\text{jt}}} * PAT_{jt} \text{ (j=region1, region 2, ..., region 30, i} \neq \text{j)}$$

$$\text{FUNDSPILL}_{\text{it}} = \frac{\text{PUB}_{ijt}}{\text{PUB}_{\text{jt}}} * F_{jt} \text{ (j=region1, region 2, ..., region 30, i} \neq \text{j)}$$

in which PAT_{jt} is the number of nanotechnology-related patents in region *j* in year *t*, and F_{jt} is the nano-funding received by region *j* in year *t*[3]. To construct the publication

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[2] There are in total 31 provincial regions in China. Tibet is not included in the analysis due to lack of data.

[3] The nano-patent collaboration data is not available, hence we use the collaboration extracted from nano-publication to create the interregional, as well as the international collaboration variable that is

weights in the above two equations we collected 164,000 Nano-publications from Thomson Reuters' Web of Science (WoS).

In addition to the collaboration weight above, we also use the geographical proximity between region to construct a second set of spillover variables. If d_{ij} is the geographical distance between regions *i* and *j*, the spatial spillover weight from *j* to *i* can be expressed as (see also Vinciguerra, et al. 2011; Ertur et al., 2006; Wang, et al. 2013):[4]

$$w_{ij} = w_{ij}^{*} / \sum_{j} w_{ij}^{*}$$

in which the distance weight w_{ij}^{*} is the inverse of squared distance[5] between region *i* and *j* ($1/d_{ij}^{2}$). Using this weight to replace the collaboration weight in the spillover equations above, we derive two additional spillover variables that capture the effect of proximity in generating spillovers.

Next, we construct an international collaboration intensity variable for capturing the effect of knowledge spillovers resulting from collaboration with foreign countries:

$$\mathrm{CI}_{\mathrm{it\_international}} = \frac{\sum \mathrm{PUB}_{\mathrm{ikt}}}{\mathrm{PUB}_{\mathrm{it}}} \text{ (k= country 1, country 2, ..., country27)}$$ [6]

where $\mathrm{CI}_{\mathrm{it\_international}}$ represents the international collaboration intensity in nanotechnology-related publications of region *i* in year *t*, $\mathrm{PUB}_{\mathrm{ikt}}$ is the number of co-authored nanotechnology-related publications involving region *i* and the foreign country *k* in year *t*, and $\mathrm{PUB}_{\mathrm{it}}$ the total number of nanotechnology-related publications stemming from region *i*. Each of the 27 foreign countries had at least 10 papers co-authored with an author based in China during the period of analysis[7]. These

defined later.

[4] In this model, spillover weight has been standardized by the row total, assuming that the amount of spillovers from *j* to *i* is subject to the spillovers i receives from other regions.

[5] Distance of provinces is measured by their capital cities, considering that a capital city is usually the central business and technology center of each province.

[6] This index is a sum of the collaboration intensity between region i and each foreign country. For instance, if region i collaborates with foreign country 1 and 2, this will be counted twice. Thus this calculation takes into consideration the number of foreign countries involved in one collaborated paper. Nevertheless, one should keep in mind that this intensity value is supposed to be slightly higher than the one calculated by directly using the number of internationally collaborated papers with region i divided by the total publications of this region.

[7] Hong Kong and Macao have different S&T systems from mainland of China and don't receive R&D

countries, in the order of the number of collaborative nano publications with Chinese regions are U.S.A., Hong Kong, Japan, Germany, Australia, Singapore, England, South Korea, Canada, France, Sweden, Taiwan, Switzerland, Spain, the Netherlands, Belgium, India, Russia, Ireland, Scotland, Pakistan, Norway, Portugal, Austria, Malaysia, Brazil, and Macao. Finally, as control variables we include regional R&D intensity (ratio of total R&D to GDP), non-nano patenting productivity (ratio of non-nano patents to R&D), and per capita income. These variables take into account regional differences in, respectively, general scientific capability, general patenting propensity, and general economic prosperity.

4. Empirical analysis and findings

In order to further set the stage for the econometric analysis, we first discuss some key aspects concerning the growth of nanotechnology across Chinese regions.

4.1 China's position in nano-science and technology

The period 1999-2010 witnessed the number of nano publications with Chinese addresses growing from 2,487, at an annual rate of 23 per cent, to 23,686. While US occupied a leading position in the early years of the emergence of nanoscience and nanotechnology, China has been able to catch-up in an impressive way over the last decade (Figure 1). Between 1999 and 2010 as the share of China increased from 6.9% to 22%, that of most other leading players dropped—from 28% to 24% for the U.S., from 13% to 8% for Germany, from 14.2% to 7.7% for Japan, from 8% to 5% for France, and from 7% to 5% for the UK. Nanotechnoy (as measured by nanotechnology patents) too has been skyrocketing in China. According to the patent records at China's State Intellectual Property Office (SIPO), the annual nano patent filing reached over 6,000 in 2010 from a meagre 98 in 1999. China's position in global nano patenting is difficult to assess, however. This is because Chinese inventors file for patents mainly locally in the Chinese patent office, with only fewer than 2 per cent of patent applications filed outside of China (Harvey, 2011).[8]

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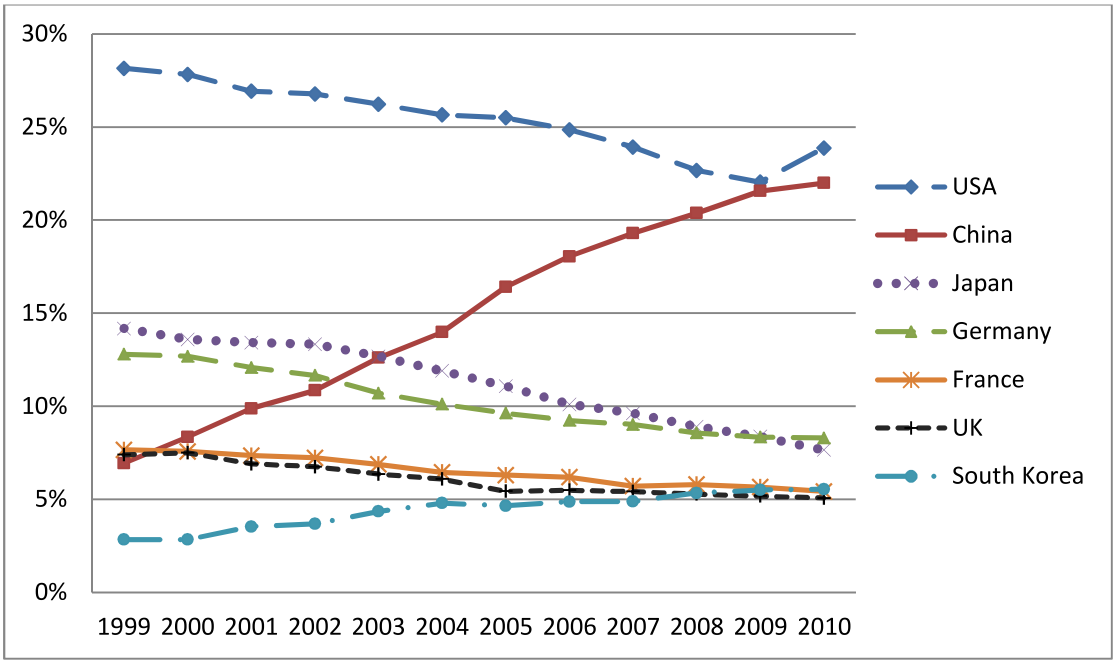
funding from Chinese government. Hence these two regions are counted as "foreign" countries.

[8] However, Chinese inventors file for patents mainly locally in the Chinese patent office, with only fewer than 2 per cent of patent applications filed outside of China (Harvey, 2011); this makes it difficult to compare China's global position with other advanced countries.

Figure 1: Share of top six countries in total nano-publications world-wide

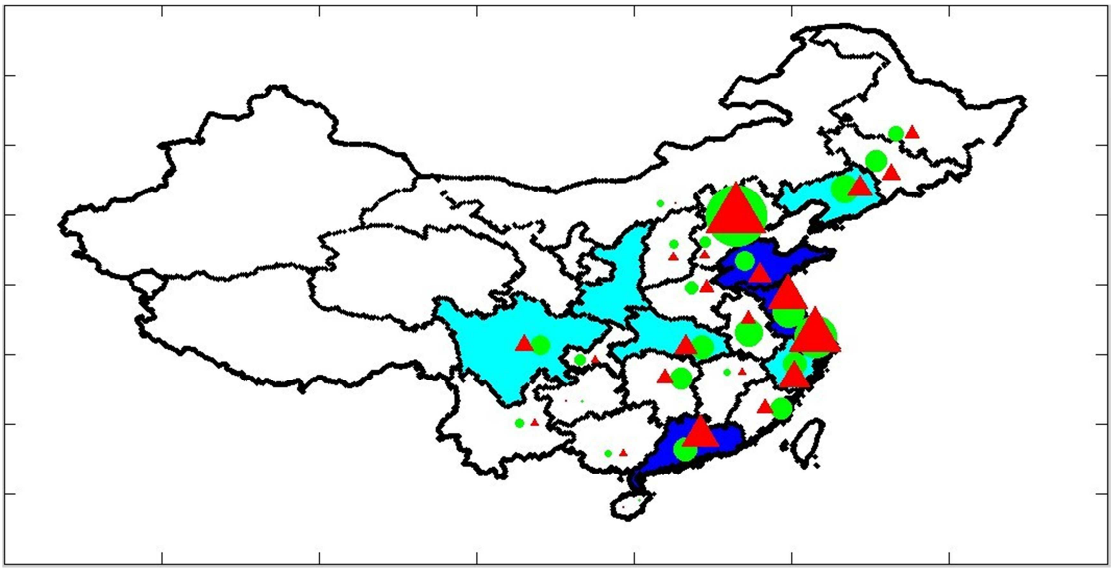


Source: Authors' own calculation based on UNU-MERIT nano-database.

Any discussion of overall growth of nanotechnology in China masks wide differences in scientific capabilities across Chinese regions. Figure 2 illustrates the strong regional disparities in nano funding, nano patenting, and technological capabilities in China over the 2000-2009 period. With their very high R&D expenditures, coastal regions in Eastern China, and a few inland regions close to them, stand out compared to the rest of China. Not surprisingly, these regions were also the biggest recipients of nano funding (green circles), and consequently led in nanotechnology-related patent applications as well (red triangles). In nano-publications, three of these regions, Beijing, Shanghai and Jiangsu, accounted for 50 per cent of the national total. In sum, regions with the highest scientific and technological capabilities, aided by large financial support from the Chinese state, became also the leading locations of nanotechnology development.

4.2 Regional disparity and changes

Figure 2: Distribution of nano patent application, nano funding and general R&D expenditure, 2000-2009



Note: 1) The presented value is the sum of 2000-09. 2) Blue shades represent the general [public plus pvt?] R&D expenditure (the darker the higher level); Green circle is nano funding (the bigger size the greater value); Red triangle represents nano patent applications (the bigger size the greater value). [instead of R&D we might show scientific publications – nano funding may be driven by publication outcome of the regions?]

To further explore this we divide Chinese regions into two categories: leading regions and lagging regions—the former category of regions are defined as those that fall into the top 25% in total scientific publications during period of study; the rest of the regions fall into the lagging category. A look at the trend in patent applications in the two categories of regions (Table 1) suggests an increasing dynamism in lagging regions. While leading regions witnessed a higher growth in nano patent applications during the first half of the period under study (1999-2004), the opposite happened during the later period (2005-2010).

Table 1: Number of patent applications and growth rates, by regional groups

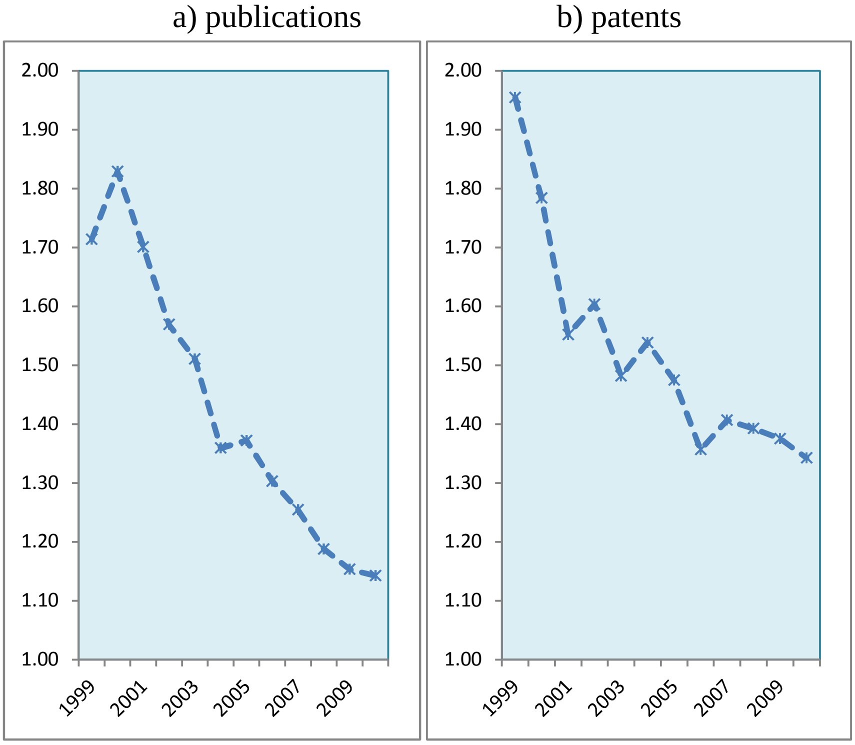
	number of patent applications			exponential growth rate	
Year	2000	2005	2010	1999-04	2005-10
Leading regions (Top 8)	189	1704	4419	55%	21%
Lagging regions	86	692	1914	52%	23%

Source: patent data from China's State Intellectual Property Office (SIPO).

Note: Leading regions are defined as those that belonged to the top 25% in total scientific publications.

Furthermore, we notice a sharp decline in the coefficient of variation in nanotechnology-related publications and patents between 1999 and 2010: respectively from 1.71 to 1.14 and from 1.95 to 1.34 (Figure 3). These evidences indicate that scientifically lagging regions have increasingly become active in nanotechnology research. The increasing dynamism shown by lagging regions in nanotechnology development requires an explanation. We focus here on the contributions of the linkages that lagging regions have with other regions within China, but also with international partners.

Figure 3: Coefficient variation of regional nano-publications and patents



Source: Authors' own calculation.

Note: 1)Tibet is not included. 2) We removed one extreme outlier: 911 patent applications in 2001 filed by a single person from Beijing. This caused Beijing to account for 85% of the national total that year.

4.3 Collaboration patterns in China

In table 2, we explore the intensity of scientific collaborations (1) among Chinese regions, and (2) between Chinese regions and the rest of the world. The top part of table 2 reveals that international collaboration intensity in scientific publications for an average Chinese region was about 19% during 1999-2004, and about 17% during 2005-2009; leading regions, understandably, exhibited a slightly higher international collaboration intensity compared to lagging regions.

Table 2: Collaboration intensity in nano-science

	1999-2004	2005-2010	comparison
	(1)	(2)	(3)=(2)-(1)
	international collaboration		
all regions	18.6	17.3	-1.3
leading regions	21.2	20.2	-1.0
lagging regions	17.6	16.2	-1.4
	national collaboration		
all regions	47.7	56.8	9.2
leading regions	37.2	39.0	1.8
lagging regions	53.6	64.8	11.1

Source: Scientific collaboration data are collected from Web of Science.

Note: Leading regions are defined as those that belonged to the top 25% in total scientific publications.

On the other hand, as the bottom part of table 2 reveals, inter-regional collaboration intensity in scientific publications was much higher for both regional categories: it was close to 50% during the first period, before increasing by about nine percentage points during the second period. Even more interestingly, leading regions on average had a much lower inter-regional collaboration intensity compared to lagging regions. The collaboration intensity in lagging regions furthermore registered an 11 percentage point increase between the two periods (as against just a two percentage point increase in leading regions) — during 2005-2009, approximately 65% of the scientific publications in an average lagging region were written with scientists based in another region. These observations lend credence to our suggestion earlier on that collaboration networks may be an important source of catching up in lagging regions; forging links with the scientific communities in other Chinese regions could help lagging regions compensate for their weak scientific capabilities.

4.4 Results and discussion

As our dependent variable is the number of nanotechnology patents, a count data model such as Negative Binomial or Poisson is more appropriate than OLS. Chinese regions exhibit wide variations in patenting so the critical assumption of the equality of mean and variance of the Poisson model does not hold. Therefore we employ Negative Binomial Regression model as our preferred model. Given especially that regional patenting can be shaped by a host of other factors that we cannot fully account for, we employ a fixed effect model. We also include a full set of year dummies to account for unobserved annual events that may affect patenting in all regions.

Table 3: Summary statistics and correlation matrix

		Mean	sd	min	max	1	2	3	4	5	6	7	8	9
1	Nano funding (log)	5.32	2.40	0	9.70	1								
2	Nanotech spillovers -Collaboration (log)	2.15	1.35	0	5.78	0.85	1							
3	Nanotech spillovers - Proximity (log)	3.86	1.21	0.55	6.41	0.52	0.67	1						
4	Funding spillovers -Collaboration (log)	3.72	1.72	0	7.80	0.89	0.96	0.62	1					
5	Funding spillovers -Proximity (log)	5.74	1.14	2.28	8.80	0.52	0.64	0.96	0.63	1				
6	International collaboration intensity (log)	15.78	9.36	0	68.20	0.19	0.18	0.07	0.2	0.08	1			
7	R&D/GDP	1.08	1.09	0.11	7.41	0.53	0.58	0.18	0.53	0.14	0.21	1		
8	Non-nano patent/R&D	1.07	0.69	0.23	5.69	-0.36	-0.43	-0.31	-0.45	-0.31	0	-0.37	1	
9	GDP per capita	1.57	1.26	0.25	6.92	0.58	0.67	0.6	0.63	0.59	0.2	0.55	-0.14	1

Note: Year dummies variables are not reported.

Table 4: Regression results of negative binomial estimations on nano patent application

	All regions			Leading regions			Lagging regions		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log of Nano funding		0.065*	0.059		0.292**	0.258*		0.027	0.028
		(0.036)	(0.037)		(0.131)	(0.137)		(0.037)	(0.038)
Nanotech spillovers –Collaboration	0.230***	0.201***		-0.249	-0.245		0.393***	0.378***	
	(0.074)	(0.075)		(0.171)	(0.167)		(0.091)	(0.093)	
Nanotech spillovers - Proximity	0.026	0.004		-0.016	-0.056		0.126	0.120	
	(0.121)	(0.119)		(0.176)	(0.163)		(0.175)	(0.174)	
Funding spillovers -Collaboration			0.128**			-0.304*			0.184**
			(0.065)			(0.169)			(0.077)
Funding spillovers –Proximity			0.127			0.078			0.265
			(0.113)			(0.161)			(0.168)
International collaboration intensity	0.003	0.004	0.003	-0.003	-0.003	-0.003	0.004	0.004	0.003
	(0.004)	(0.004)	(0.004)	(0.009)	(0.009)	(0.009)	(0.004)	(0.004)	(0.004)
Control variables									
R&D/GDP	0.153***	0.140***	0.160***	0.246***	0.179***	0.164***	0.010	0.010	0.101
	(0.044)	(0.044)	(0.043)	(0.056)	(0.062)	(0.061)	(0.114)	(0.113)	(0.110)
Non-nano patent/R&D	0.076	0.089	0.105*	0.174**	0.140*	0.139*	-0.069	-0.052	0.017
	(0.062)	(0.061)	(0.060)	(0.079)	(0.080)	(0.080)	(0.105)	(0.107)	(0.110)
GDP per capita	0.009	0.013	0.027	0.135**	0.145***	0.128**	-0.037	-0.034	-0.005
	(0.034)	(0.034)	(0.033)	(0.053)	(0.051)	(0.052)	(0.069)	(0.069)	(0.064)
Constant	2.320***	2.047***	1.225	4.152***	2.093	2.405	1.759*	1.632	0.521
	(0.664)	(0.671)	(0.794)	(1.033)	(1.371)	(1.487)	(1.033)	(1.041)	(1.258)
Observations	330	330	330	88	88	88	242	242	242
Number of regions	30	30	30	8	8	8	22	22	22

Note: 1) Dependent variable is nano patent applications. 2) Explanatory variables are lagged by one year; 3) Year dummies are not reported. 4) *** at 1% significance level; ** at 5% significance level; and * at 10% significance level.

Summary statistics and correlation matrix are reported in table 3 and the regression results are documented in table 4[9].

All models include the full set of controls and year dummies. Models 1 to 3 present results based on the complete sample with different combinations of the key explanatory variables. In Model 1 we include the two nanotechnology spillover variables: in one spillovers stem from formal collaboration linkages, and in the other, from regional proximity. The results confirm that formal collaborations generate knowledge spillovers; however, proximity has no significant effect. This is not surprising given the vast distances separating Chinese regions. In model 2 we add the nano-funding variable. This variable has a positive and significant coefficient, suggesting that direct financial support for nanotechnology research has had a positive impact on the development of this technology in Chinese regions. In model 3, we replace the nanotechnology spillover variables (proximity-induced and collaboration-induced) with those based on funding. Note that the two sets of variables could not be simultaneously included in a single model due to the high collinearity between them. The results are similar – funding generates inter-regional spillovers through collaboration networks, but not through proximity.

Next, we carried out separate analysis for leading and lagging regions[10]. Results for leading regions are presented in models 4 to 6, and those for lagging regions in models 7 to 9. Comparison of the results for the two categories reveals interesting insights. First, direct funding has a significant positive effect on patenting only in leading regions (model 5 and 6), not in lagging regions (model 8 and 9). This is consistent with our earlier discussion in section 4 that advanced regions led in both nano funding and nano patenting. Confirming this further, Figure 4 illustrates a substantially superior association between nano funding and nano patenting in leading regions compared to in lagging ones.

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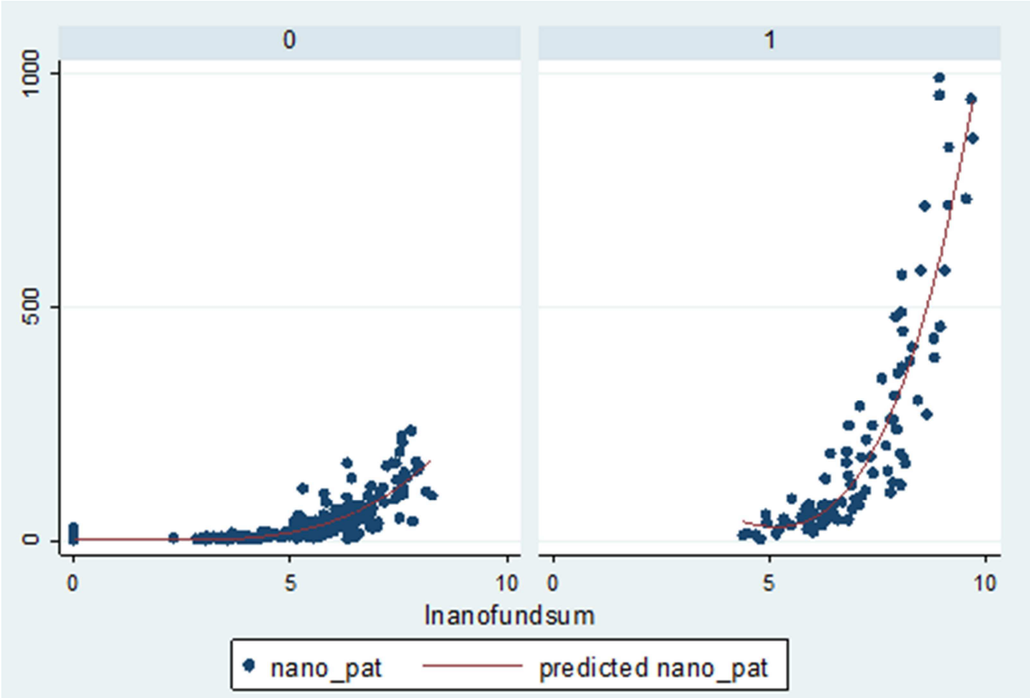
[9] Regression results stay similar if we separate collaboration and proximity variables into different models. Results are available upon request.

[10] As noted before, leading regions are defined as those that belonged to the top 25% in total scientific publications. Different definitions of scientific capabilities such as nano publications, nano patents, and total patents yielded similar results as in table 4.

Figure 4: nano patent application and nano funding



Note: 0 – lagging regions, 1 - leading regions.

Contrary to the effects of nano funding, spillovers from other regions through collaborations exerted a significant positive impact in lagging regions (model 7, 8 and 9), but not in leading ones (model 4, 5 and 6). This applies for both nano-technology and nano-funding spillovers. These results too are in line with our earlier discussion, demonstrating that collaboration linkages with other regions compensate for the weak capabilities of lagging regions and the low degree of government support they receive. Advanced regions, being the front runners of nanotechnology development, are able to capitalize on governmental support, leveraging their own capabilities.

The international collaboration intensity variable shows little noticeable influence, with negative, though non-significant, coefficients for leading regions. This supports the standard view that the surge of nano patent applications in China was driven by China's indigenous capability, in particular in its leading regions. More broadly, the results are in agreement with the notion that in the development of new technologies, national linkages are likely to be more effective than international ones (Metcalfe and Ranlogan, 2008).

5. Conclusions

Over the past two decades, China has been attempting to make a giant leap in nanotechnology development. Given China's strong scientific capabilities as reflected in the presence of a number of world class universities and research institutes, already in the late 1990s China was projected to be a leader in emerging science-based technologies such as nanotechnology (Porter et al. 2002). True to these predictions, China has fast emerged as a leading global player in nanotechnology. The evidence presented in this paper suggests that China's success in nanotechnology development in general owes in large part to the fostering of indigenous scientific capabilities through strong financial support from the state.

Our analysis also revealed that the dynamics of nanotechnology development were quite different in regions leading in versus those lagging in scientific capabilities. It is indeed well known that economic development and scientific capabilities are highly uneven across Chinese regions. Sure enough, a few regions with superior scientific capabilities spearheaded the early growth of nanotechnology in China. However, regional inequalities in nanotechnology development are diminishing. In this regard, our study has found that the key source of growth in nanotechnology patenting in lagging regions was the collaborative ties that scientists from these regions forged with those from other regions. These collaborative ties generated significant inter-regional spillovers of nanotechnology knowledge. In leading regions, on the other hand, R&D support received from the government for nanotechnology development was the principal factor behind the rapid growth of nanotechnology output. Spillovers from other regions, or from abroad, played no significant role in the growth of nanotechnology in these regions.

Our study contributes to the catch up literature by highlighting on the one hand how targeted governmental support can help leading regions spearhead the growth of a new technology system, and on the other the role of region-spanning scientific collaborations in helping lagging regions partake in the development of these technologies. The study furthermore contributes to the economic geography literature on knowledge spillovers in that future studies may place greater emphasis on the differences in growth dynamics in leading and lagging regions.

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