Research Policy 42 (2013) 765–775

Contents lists available at SciVerse ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Building global-class universities: Assessing the impact of the 985 Project

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ARTICLE INFO

Article history:
Received 24 August 2011
Received in revised form 1 August 2012
Accepted 11 October 2012
Available online 22 November 2012

Keywords:
Chinese universities
National innovation system
985 Project
Publications

ABSTRACT

In 2006 China had become the fifth leading nation in terms of its share of the world's scientific publications. Today it is second only to the United States. This achievement has been accomplished in part by a conscientious effort by the government to improve the research performance of China's universities through a series of programs, the most important of which is the 985 Project. This paper considers the effects of the 985 Project on increasing the rate of publication in international journals by researchers at 24 universities. Using the approach of linear mixed modeling, it was found that the rate of growth in publications by lower tier universities exceeded that of China's two most highly regarded universities after controlling for university R&D funding, university personnel size, and provincial per capita income. It was also found that the rate of growth of publications for universities as a whole increased more quickly after the implementation of the 985 Project.

1. Introduction

China's emergence on the global economic map has been nothing short of remarkable. While the economic success has been undeniable, there has been ample criticism of a putative lack of innovative capability and backwardness in terms of global scientific contribution. Undoubtedly, historically Chinese universities have been under-funded and overly concentrated on undergraduate training, while making minimal contribution to the global scientific community (Hayhoe, 1987). By the late 1980s, Chinese policymakers had become seriously concerned about a perceived relative technological backwardness and launched programs meant to strengthen the nation's technological and scientific capabilities (Feigenbaum, 2003; Hu and Mathews, 2008; Jakobson, 2007; Segal, 2003). As the economy grew, largely on the basis of providing low value-added manufacturing, political leaders came to believe that better university research and graduate training were necessary, as part of an integrated economy-wide strategy for overcoming the nation's technological backwardness (Hayhoe, 1996) and building a technically trained workforce (see, for example, Simon and Cao, 2009). There seems to have been near unanimous agreement that this catch-up was critical to realizing the goals of the Chinese leadership (see, for example, Feigenbaum, 2003).

This consensus motivated the adoption of policy measures to overcome what had been identified as seriously inadequate research productivity in Chinese universities. In 1998, the shift in emphasis was announced by then Chinese President Jiang Zemin at the Centenary Celebration of Beijing University. The centerpiece of this shift was a massive new program commonly known as the 985 Project, whose specific goal was to improve the global standing of a select group of Chinese universities. Given the ambitious goals, enormous size, and global implications of this effort, this paper examines the program's results.

The outcome of the Chinese effort is significant because universities throughout the developing world are being called upon to play a more active role in upgrading their national innovation system. It is also of interest because, in contrast to the other East Asian developing nations, China is investing in university research quite early in the economic development process. For example, in both the case of Taiwan and Korea, only recently has research performance become an important goal. Prior to this, the university's main role was to provide trained personnel (Hu and Mathews, 2008). To improve their universities' performance the Chinese government is undertaking a massive program of selective investment, not so much with the goal of increasing their size, but more narrowly focused on improving the research quality of its universities.

In percentage terms, the 985 Project initiated by the Chinese government is a critical component of one of the largest sustained increases of investment in university research in human history. To illustrate, from 1999 through 2008, the compound annual growth rate (CAGR) of Chinese university R&D expenditures was 22% – a sum that exceeding the 15% CAGR of GDP (Ministry of Science and Technology, 1999–2009).[1] This rate of growth in university R&D

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[1] University R&D has ranged between 8.5% and 10.5% of China's total R&D between 1999 and 2008, and the annual growth rate of both has been close to identical, with university R&D growing at 22.4% and total R&D growing at 23.7% annually.

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http://dx.doi.org/10.1016/j.respol.2012.10.003

expenditures is greater than was that of the U.S. in the immediate post-Sputnik era[2] – an era that propelled U.S. research to global pre-eminence (see, e.g., Geiger, 1993; Graham and Diamond, 1997). This is the result of the Chinese government's decision that the growth rate of education finance funding from governments at all levels should exceed the growth rate of their regular revenue (Education Law of the People's Republic of China, 1995). In a pioneering work, Zhou and Leydesdorff (2006) examined the efficiency of overall national growth in investment in terms of the number of international Science Citation Index (SCI) publications. They found that the increase in funding through 2007 was efficient in that funding growth was converted into publication growth. While their results apply to the Chinese R&D system as a whole, this paper, using a previously unexploited database of Chinese government statistics, considers the effects of the 985 Project on increasing the rate of publication in international journals by researchers at 24 individual 985 universities under the purview of the Ministry of Education.[3]

Due to the enormous size of this policy experiment, and the importance to China of building a trained workforce of individuals capable of participating in the global technological and scientific community, understanding the results of the 985 Project should be of great interest to many, not least in developing nations intent on improving R&D capabilities.

2. Placing Chinese science in a global perspective

The Chinese economy has experienced rapid growth and built an export-oriented national production system linked by global value chains to the world's leading economies (Hu and Mathews, 2008; Breznitz and Murphree, 2011). Chinese government policy has aimed to transform the economy from one based on producing lower value-added products and being dependent upon intellectual property owned by foreigners (Dobson and Safarian, 2008), to one in which China also performs higher value-added functions in the value chain (Breznitz and Murphree, 2011). The Chinese government, whose leadership today is dominated by leaders with engineering or science backgrounds, has accepted the premise that its national innovation system must begin producing global-class science and technology as the foundation for long-term economic development. As a result, strategies for enhancing national research and innovation capabilities occupy an increasingly important position in China's development policy (Wu, 2006).

The current Chinese approach to upgrading its national innovation system differs from most advanced nations, and in particular the earlier East Asian Tigers (Hu and Mathews, 2008; Sohn and Kenney, 2007) within which research institutes and industry were the major source of innovation. Given the limited innovation capacity of Chinese firms, the government has turned to research institutes and universities as a source of capabilities for addressing industry's practical problems (Hong, 2006, 2008). Also, in contrast to these other economies, Chinese policy makers are motivated by a sense that China should assume a position among the global scientific powers to accompany and reinforce its increasing economic and political power.

The extensive role of public-supported research institutions in performing industrial R&D in China has a long history. Prior to the reforms of the 1980s, research institutes had the primary responsibility for conducting national R&D (Liu and White, 2001). Traditionally, industry relied heavily upon research institutes and, to a lesser degree, universities for technology improvement (Hong, 2008) and only recently has this changed as some firms, such as Huawei, have begun to invest heavily in their own R&D.[4] With economic reforms, increasing involvement in the global economy, study of the R&D systems of other nations particularly the U.S., and an awareness of the need to rapidly improve China's technological expertise, it was decided that Chinese universities should play a greater role in performing research (Wu, 2006; Fischer and Zedtwitz, 2004; Orcutt and Shen, 2010).

Another unique feature of Chinese national innovation system (NIS) is that universities and research institutions (URIs) own enterprises (see, e.g., Chen and Kenney, 2007; Eun et al., 2006; Kroll and Liefner, 2008; Liu and Jiang, 2001). There have been some successful enterprises, such as the University of Beijing's Founder Group, Tsinghua University's Tong Fang, and Legend/Lenovo, established by computer technology personnel from Chinese Academy of Science, that can be directly traced to URIs and which have contributed substantially to the upgrading of the economy's technological capabilities. However, recently many URIs have been reducing their involvement and investment in business activities and have moved away from financing and controlling spin-off enterprises (Kroll and Liefner, 2008).

As one might expect in a dynamic and evolving NIS, the role of Chinese universities has been changing. Initially, their paramount role was providing trained personnel for industry. Later, they were expected to provide technical problem-solving for the private sector. Most recently, although the earlier goals remain, expectations are that they will conduct research that is recognized internationally.

The Chinese strategy for building its national innovation capacity differs from that of the East Asian Tigers (Korea, Singapore, Taiwan and Hong Kong). The Tigers depended to a far greater degree on key private firms and government research institutes, as universities were until very recently devoted to teaching (Hu and Mathews, 2005). In contrast, while encouraging both domestic and foreign firms to increase domestic research and continuing to support the research institutes, China has dramatically increased its investment in university research in the pursuit of developing a knowledge-based economy (Leydesdorff and Zeng, 2001).

The expansion of Chinese publications in international journals has been extraordinary (Leydesdorff and Wagner, 2009). For example, Fig. 1 shows article publications in Science Citation Index (SCI) journals of major countries from 1989 to 2009. The growth trajectory of China is striking, as it overtook the UK in 2008 and only trails the US. In 1989 the number of SCI papers by Chinese authors was only 3% of the number by U.S. authors. By 2008 this proportion had risen to 30% of the number by U.S. authors. As a point of comparison, publication by Italian and French researchers experienced only slow growth resulting in a drop in their global share. The United Kingdom, Germany, and Japan managed to retain their overall share. The nation experiencing the greatest growth in publication share was China. A recent report by the Royal Society (2011: 43) indicated it was possible that China could overtake the U.S. in terms of the sheer number of scientific publications as early as 2013 or, more probably, in 2020. In some specific areas, such as nanotechnology, China has become the world's second leading producer of nanotechnology research articles in number, and in one account, may be on the way to becoming the leader by 2012 (Lenoir, 2011). In overall terms of article citations published by their scientists, though, the U.S., in particular, and to a far lesser degree the United Kingdom, maintain enormous leads.

[2] For example, from 1958 through 1968 U.S. university R&D had a 16% CAGR.

[3] The limitation of the study to universities managed by the Ministry of Education is necessary because data for the other universities is not reported in a comparable fashion.

[4] One measure of this is that from 2006 to 2010 of the top fifteen U.S. Patent and Trademark Office (PTO) filing employers in China filing for patents at the U.S. Patent and Trademark Office, only three were Chinese firms, though the general category "individuals" was the second largest filer (USPTO, 2011).

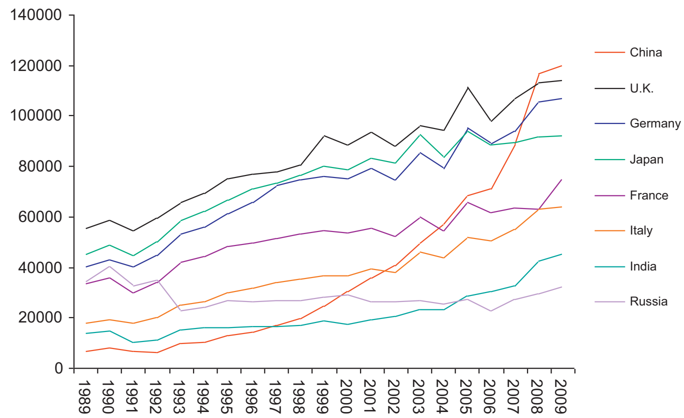

Fig. 1. Science and technology papers indexed by SCI in selected countries, 1989–2009.

Source: China Science and Technology Statistics Data Book, 1999–2009. http://www.sts.org.cn/.

Chinese investment in university R&D has increased rapidly. As Fig. 2 indicates, China's R&D investment in 1992 was approximately 2% of that of the U.S., and while U.S. university R&D increased at approximately 6% per year, Chinese university R&D increased far more quickly and by 2009 was nearly 12% of that of the U.S. Importantly, this comparison is in terms of nominal dollars and not purchasing power parity. The reason we chose to use nominal dollars is that, while labor costs are dramatically lower in China, scientific equipment and other inputs may be the same or even more expensive as they are often imported. What is abundantly clear is that China is investing considerable resources in its universities and this is having an impact.

3. The Key University Project, 211 Project, and 985 Project

The core policies for Chinese universities are set by the central government. During the 1990s the central government gave increasingly higher priority to improving the higher education system, seeing it as serving a central role in the modernization process. Higher education was expected to assist in economic development, assist existing firms in becoming more competitive, and actively develop university-run high-tech industries (Ministry of Education, 1993a,b). More recently, beyond these economic benefits, having global-class universities has symbolic importance as China strives to assert its status as a global leader.

Western-style universities have a comparatively short history in China with the first ones being established in the 1890s. Throughout the twentieth century Chinese governments have consistently pursued a policy of investing in a set of chosen elite institutions, and these institutions have historically been centered in the major Chinese cities. Tsinghua University, which has become China's premier technical university, was established in 1911. By 1920, though most major cities had universities, the Chinese university system was concentrated in Beijing and Shanghai. After the Chinese Revolution and the importation of the Russian research institute model, universities were largely relegated to teaching. In 1954, Ministry of Education (then the Committee of Education) embarked upon a policy of developing "key universities," which initially focused on strengthening six universities (Ministry of Education, 1954).[5] In 1959 the Central Committee of the Communist Party issued a new policy *The Decision on Building up a Number of Key Universities*, which identified 10 more universities in addition to the six originally chosen (Central Committee of the Communist Party, 1959).[6] In 1960 the number of key national universities expanded once again to 64. However, from 1966 to 1976 all universities in the country were closed as China experienced the Cultural Revolution and education emerged as a core battlefield. As part of reopening the universities, in September 1977 the Ministry of Education reinstituted college entrance examinations. With the reopening of universities, the Chinese government in 1978 increased the number of key universities to 88, of which Beijing, Tsinghua, and Fudan Universities were ranked at the topmost (Ma, 2007: 32).

Since the 1990s, a series of major higher education policy initiatives have aimed at building world class universities. The 211 Project was entitled "High-level Universities and Key Disciplinary Fields" project[7] and 985 Project was entitled "World Class Universities." They were initiated with the purpose of building the research capacity of Chinese universities. The 211 Project included 107 universities and allocated each university 400 million RMB to "improve teaching, learning and research" (Ma, 2007: 33). As part of the 211 Project provincial and local governments also invested in the selected universities (Ministry of Education, 2007).[8]

In the May 1998 speech launching the 985 Project, the then Chinese President Jiang Zemin declared that "China must have a number of first-rate universities with an advanced level internationally" (People Online, 1998).[9] In 1999, the Chinese government published *the Action Plan for Invigorating Education on 21st Century*, which formalized the goal of developing "world-class" universities and departments (Ministry of Education, 1999). With the establishment of the program, developing world-class universities became a national strategic objective and one of the primary tasks of higher education. The 985 Project was conceived of as a partnership with funding appropriated by the Ministry of Education (MOE), provincial and municipal governments, and from ministries that had their own universities. Universities entered the program on different dates and the funding was differentially distributed. Beijing and Tsinghua University each received 1.8 billion RMB from the central government, and have each been allocated 0.3, 0.6,

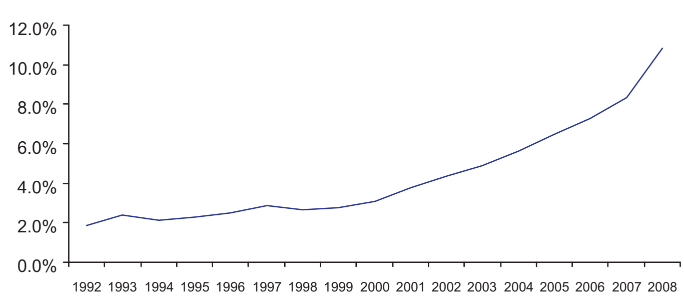

Fig. 2. University R&D expenditures: China as a percentage of U.S., 1992–2008.

Source: National Science Foundation, Division of Science Resource Statistics, Survey of Research and Development Expenditures at Universities and Colleges. FY 2008. Data for China is from China Science and Technology Statistics Data Book.

[5] They are Beijing University, Tsinghua University, Beijing Agriculture University, Renmin University, Beijing Medical College and Harbin Institute of Technology – all of which are in Northern China.

[6] Four of these universities were in Shanghai; Fudan University, Shanghai Jiaotong University, Huadong Normal University, and Shanghai Medical College, and three were in Beijing; Beijing University of Technology (now Beijing Institute of Technology), Beijing College of Aeronautics and Astronautics (now Beijing University of Aeronautics and Astronautics), and Beijing Normal University. The remaining three were Xi'an Jiaotong University, Tianjin University, and the University of Science and Technology in China.

[7] For further information on the 211 Project, see "211 Project" Overall Developing Plan (Ministry of Education and Ministry of Finance, 1995).

[8] The total investment for 211 Project totaled was 36,836 billion RMB from 1995 to 2005. This was parceled out in following manner: 16,541 billion RMB was used in key discipline construction, and 7.1 billion RMB was expended for the establishment of a system of public service, and 2409 billion RMB was appropriated to strengthen the teaching staff, and 10,771 billion RMB was allocated for infrastructure building.

[9] The 985 Project obtained its name from the date of the project announcement.

0.9 billion RMB in 1999, 2000 and 2001. The rest of the universities received central government funding from 0.1 to 0.6 billion RMB according to various contracts between local provinces, the MOE, and universities. The provincial governments were expected to match the funds from the central government on a 1:1 or 0.8:1 basis.[10] In 985 Project Phase I (1999–2003), special funding of the central government amounted to 14 billion RMB allocated to 34 universities, and in Phase II (2004–2007) special funding of the central government increased to 18.9 billion RMB allocated to 39 universities (Ministry of Education, 2011). In 2011 both the 985 Project and the 211 Project were closed to new universities (Yuan and Zhang, 2011).

The 985 Project universities are unevenly distributed throughout the nation – of the 24 universities examined in this study, three are located in Beijing, three are in Shanghai, two are in Guangzhou, and another 9 are located in eastern capital cities. Only seven universities in the program are located in Western and Central, China.

The research performance of Chinese universities has attracted comparatively little scholarship despite its growing international significance. There are exceptions. For example, using data envelopment analysis (DEA) and data from 1993 to 1995, Ng and Li (2000) examined the research performance of 84 Chinese institutions of higher education after the implementation of education reform in 1985. They concluded that there were variations by regions and that regional economic performance played a significant role in the institutions' research performance. The Medium- and Long-term Education Reform Plan (2010–2020) proposed accelerating the improvement of Chinese universities to world-class level with first-rank departments through the continuation of 211 and 985 Projects (The Communist Party of China Central Committee and The State Council, 2010). The overall goal was by 2020 to have a group of globally recognized universities with several at or near world-class levels of excellence.

In another application of DEA, Johnes and Yu (2008) studied 109 Chinese universities with data from 2003 and 2004, a period during which Chinese universities experienced rapid expansion in terms of undergraduate and graduate student enrollment, increased government funding, as well as a rapid growth in patenting (Li, 2012). Their study confirmed that poor regional economic performance had a negative effect on university research performance.

Zhang et al. (2011) measured changes in productivity and technological efficiency of research institutions of the Chinese Academy of Science after the project of Knowledge Innovation Program (KIP). They found that the reform reduced the gap between leading and lagging institutions in terms of management and operation, but that those located in Beijing and Shanghai performed better than those in other regions.

The 985 Project is not only a funding program, but also a project that aims to bring about fundamental transformations to a subset of educational institutions (Li et al., 2012). It is explicitly directed toward building world class universities which by necessity requires a focus on a limited number of universities and allocates preferential funds as a support for development, but there is also a component directed to improve the standing of less highly ranked universities outside of Beijing and Shanghai. Like Zhang et al. (2011), this study specifically investigates the extent to which lower-ranked institutions have performed as a result of the implementation of a national program relative to national leaders. In our case the institutions are universities, and the national leaders are Beijing University and Tsinghua University.

Our performance measure is publications in foreign journals – one of the key stated metrics for the 985 Project and the Chinese government. The government's goal is not simply to publish more, but rather to improve international visibility of the publications. A further consideration is that international publications operating with peer review enforce a quality standard that institutionally sponsored national journals may be unable to achieve.[11]

The data on publications in foreign journals by Chinese university affiliated authors differs from the commonly used SCI paper database. The data employed in this study on foreign publications has been collected annually by the Ministry of Education (MOE). Foreign journals are defined by MOE as all foreign, non-Chinese, language journals. As such this definition contains journals not included in the SCI.[12]

4. Data and analysis

The twenty-four 985 universities in this study can be categorized into three tiers on the basis of their inclusion into the 985 Project and their reputations as universities. Tier 1 is comprised of China's two elite universities, Beijing University and Tsinghua University, which both entered the 985 Project in 1999. Tier 2 is comprised of five universities that also entered into the program in 1999, but have international rankings below Tier 1. These universities have been chosen for development to achieve international recognition. Tier 3 consists of a group of 17 universities that entered the 985 Project after 1999 and were targeted for development as national universities.[13]

For the most part, these groupings parallel the academic ranking of these universities in Table 1, which is drawn from the Academic Ranking of World University (hereafter, ARWU) published by Shanghai Jiaotong University (2012) and which was initiated in 2003 specifically for the purpose of measuring the gap between Chinese universities and world-class universities.[14]

Only eight Chinese universities were ranked among the top 500 universities in the world in 2005. By 2010 this number had increased to 22, with more than half in the aggregated 400–500 ranking. This includes 19 of the 985 universities.[15] Initially, Tsinghua and Beijing Universities were ranked in the top 300 universities, but by 2010 they joined the group of universities that were ranked between 151 and 200. The second tier of universities are now in the top 200–400 universities in the world with one exception, Xi'an Jiao Tong University, which is ranked between 401 and 500. The third-tier 985 universities include five that were not ranked in the global top 500.

As indicated above the growth of Chinese research as measured by academic papers is remarkable. To appreciate this phenomenon it is useful to compare this university research output with the major inputs to this effort; the number of research personnel and

[10] The share contributed by the provincial governments was formalized through agreements between the Ministry of Education and various provincial governments.

[11] Chinese journals have diverse rating, but most have lower citation rates than comparable international journals (Zhou and Leydesdorff, 2006).

[12] Simon and Cao (2012) provide a very useful guide on the organization, availability, and reliability of Chinese government science and technology statistics for scholars working with this data.

[13] This is not the only way in which Chinese universities have been classified. Zhu and Liu (2009) classified all universities into four classes based on inclusion or exclusion from the 985 and 211 Projects. In this paper, since we focus on 985 Project universities, we use a population of 24 universities all of which are managed by the Ministry of Education.

[14] The ARWU ranking system has 4 criteria; quality of education, quality of faculty, research output, and per capita performance. In contrast to most other rankings, the ARWU ranking system focuses only on research results and the ranking methodology is transparent (Shanghai Jiaotong University, 2012).

[15] Three internationally ranked universities in China that are part of the 985 Project but were excluded from our study are China Agricultural University, Harbin Institute of Technology and the University of Science and Technology of China. The latter two were excluded because they are not under the responsibility of the MOE. China Agricultural University is under the MOE, but it did not become a 985 university until 2006.

Table 1
Academic ranking of world universities of 985 project universities: 2003 through 2010.

Tier	University	2003	2004	2005	2006	2007	2008	2009	2010
1	Tsinghua	201–300	202–301	153–202	151–200	151–200	201–302	201–302	151–200
1	Beijing	201–300	202–301	203–300	201–300	203–304	201–302	201–302	151–200
2	Zhejiang	301–400	302–403	301–400	201–300	203–304	201–302	201–302	201–300
2	Nanjin	301–400	302–403	301–400	301–400	203–304	201–302	201–302	201–300
2	Shanghai Jiao tong	401–500	404–502	301–400	201–300	203–304	201–302	201–302	201–300
2	Fudan	301–400	302–403	301–400	301–400	305–402	303–401	303–401	201–300
2	Xi'an Jiao tong	–	–	–	–	–	–	–	401–500
3	Shandong	401–500	–	–	401–500	403–510	402–503	303–401	301–400
3	Sun Yat-Sen	–	–	–	–	403–510	402–503	402–501	301–400
3	Sichuan	–	–	–	–	–	402–503	402–501	301–400
3	Jilin	401–500	404–502	401–500	401–500	305–402	402–503	402–501	401–500
3	Nankai	–	–	–	–	403–510	402–503	402–501	401–500
3	Tianjin	–	–	–	–	403–510	402–503	402–501	401–500
3	Lanzhou	–	–	–	–	403–510	402–503	402–501	401–500
3	Huazhong U of S&T	–	–	–	–	–	402–503	402–501	401–500
3	Dalian U of Tech	–	–	–	–	–	402–503	402–501	401–500
3	Southeast	–	–	–	–	–	–	–	401–500
3	Wuhan	–	–	–	–	–	–	–	401–500
3	Xiamen	–	–	–	–	–	–	–	401–500
3	Ocean U of China	–	–	–	–	–	–	–	–
3	Tongji	–	–	–	–	–	–	–	–
3	South China U of Tech	–	–	–	–	–	–	–	–
3	Beijing Normal	–	–	–	–	–	–	–	–
3	Chongqin	–	–	–	–	–	–	–	–

Source: Shanghai Jiaotong University, various years. http://www.arwu.org/.

Table 2
University annual average values and annualized growth rates over selected years.

Average annual count for all 24 universities	1993–1998 annual growth rate	1998–2002 annual growth rate	2002–2006 annual growth rate	2006–2010 annual growth rate	1993–2010 annual growth rate
Publications in foreign journals	10.6%	13.5%	20.6%	14.9%	14.6%
Research and development expenditures	20.6%	27.4%	19.1%	20.8%	21.9%
Science and technology personnel	−1.3%	9.2%	−1.8%	2.1%	1.8%

Source: Compilation of Basic Statistics for Universities Directly under the Ministry of Education (1993–2010).

the amount of R&D of the 24 universities in this study. Table 2 presents these data for selected years from 1993 to 2010, along with the annualized growth rates for these time periods. The final column of Table 2 indicates the growth rate over the entire time period of this study, 1993 through 2010.

Both the average number of foreign publications and R&D expenditures grew at quite robust rates over the entire time period. The university average of these measures has an annualized growth rate of 14.6% and 21.9% respectively over the entire period. Science and technology (S&T) personnel is the exception to the significant growth rates of the other three variables. The average number of S&T personnel of these universities grew at an anemic 1.8% between 1993 and 2010.

4.1. Publication growth rates over time and across university tier

The publication growth rates of each tier can be determined by regressing the natural log of average publications on the year of publication. If it assumed that the growth rate is constant, this approach yields a consistent growth estimate for university publications over the entire period under consideration.

Regressing the natural log of average publications on year for all universities in our study produces the following ordinary least squares estimate.

$$\ln \text{Articles} = 5.221 + 0.145\text{year} \quad (1)$$

The coefficient on year is simply the exponential rate of annual growth of average publications over the entire time period, and indicates that the publication average of all 24 universities in our study grew at an annual rate of 14.5% over the years 1993 through 2010.

Applying the exponential function to both sides of Eq. (1) yields an exponential growth function that can be compared with actual observations of average university foreign publications over time. Fig. 3 shows this comparison.

The assumption of a constant growth rate in average publications holds quite well for all universities. This specification accounts for over 95% of all observed annual average publications at these universities.

Figs. 4–6 provide the fitted exponential growth curves and observations for Tier 1, 2 and 3 universities respectively. In Fig. 4

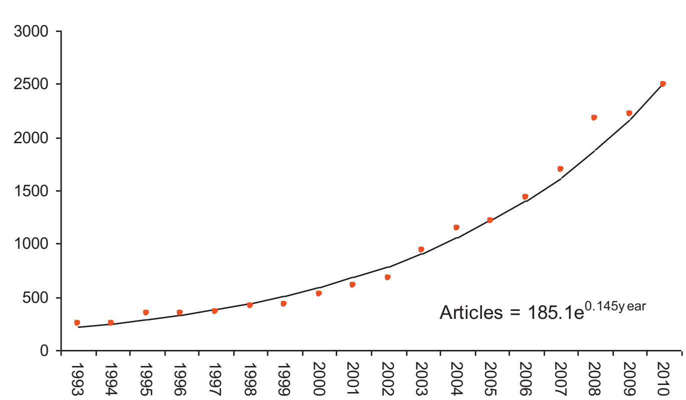

Fig. 3. All Universities' average number of articles in foreign journals, 1993–2010. Source: Authors' calculations.

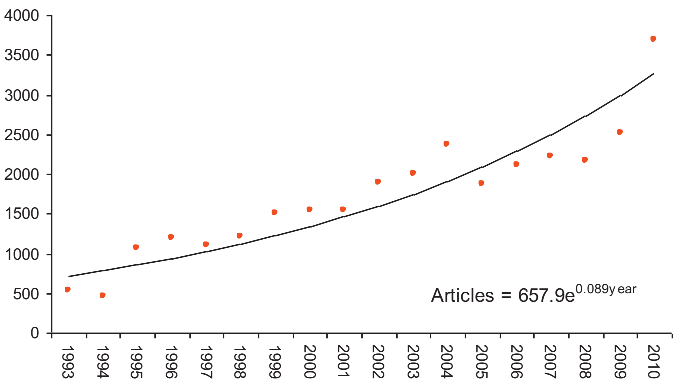

Fig. 4. Tier one universities' average number of articles in foreign journals, 1993–2010.
Source: Authors' calculations.

Tier 1 is comprised of just two universities, Beijing University and Tsinghua University, and the observed average of these two only roughly follows the estimated curve over time. The annual growth rate of average publications for Tier 1 was just under 9%. Given the higher level of foreign publications by these two elite universities in 1993, this lower growth rate is not surprising.

The publications of the Tier 2 and Tier 3 universities are shown in Figs. 5 and 6. The observed averages of these university tiers follow the estimated growth curve quite closely with the exception of the final years of data, which suggests a possible acceleration in publications as the observed averages are above the estimated curve for the years 2008 and 2009 for Tier 2, and above the estimated curve in 2007 and 2008 for Tier 3.

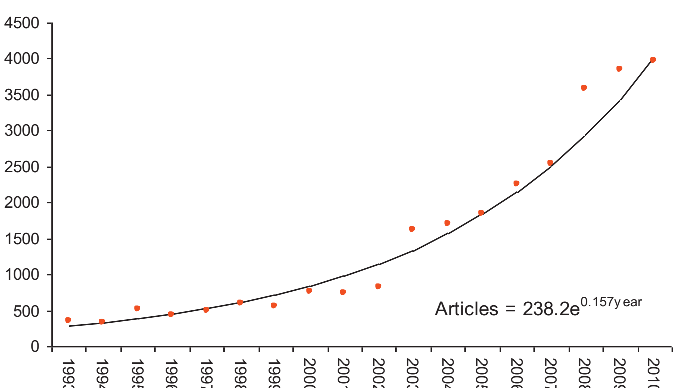

Fig. 5. Tier two universities' average number of articles in foreign journals, 1993–2010.
Source: Authors' calculations.

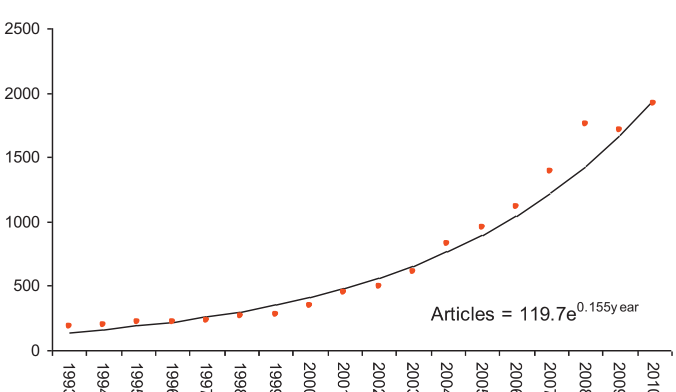

Fig. 6. Tier three universities' average number of articles in foreign journals, 1993–2010.
Source: Authors' calculations.

These results indicate that the lower tier universities are increasing the number of publications in foreign journals at a faster rate than are the Tier 1 universities. Tier 2 universities grew at a rate of 15.7%, while Tier 3 universities on average increased their number of publications by 15.5% annually. At this level of analysis it is difficult to say much more. To obtain a more accurate view the publication output of each individual university, together with university specific characteristics and control variables, is examined in the following section.

4.2. Linear mixed modeling of university publication output

Although the 24 universities studied here were all selected to be part of the 985 Project, they vary greatly in size and research capacity. There is considerable variation within the second and third tiers as well. The statistical methodology used measures the impact of the 985 Project, which can be seen as a treatment for all of the universities despite their differing initial endowment. We are able to control for faculty size and R&D expenditures at each university for the years before and after the implementation of the project, as well as accounting for provincial income. The statistical approach that is most applicable to assessing the 985 Project is linear mixed modeling.

Linear mixed models are characterized by having both fixed effects, which are common to all units of observation, and random effects which are unique to each unit of observation. The fixed effects are directly comparable to standard linear coefficients and provide inferences as to the effects of these variables on all units of observation, which in this case are the universities of the 985 Project. Random effects take the form of random intercepts or random coefficients that apply to each individual university (Stata, 2009: 308).

The publishing performance in this study differ greatly among these universities, as do the rates of growth of publications over time. A comparison of these universities is given in Fig. 7, where the number of foreign publications in 1993, and the rate of growth of foreign publications from 1993 through 2010 is presented for each university.

As Fig. 7 demonstrates there is a mild inverse relationship between the initial capacity of these universities to produce publications, and the rate of growth of publications. This supports the earlier observation that lower tier universities have increased their

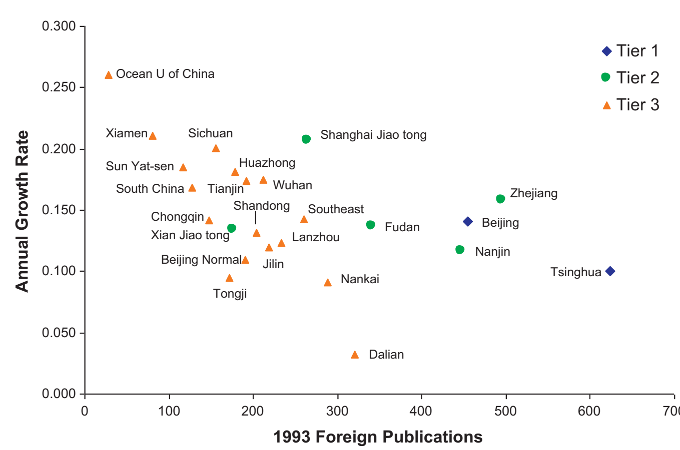

Fig. 7. Foreign publications in 1993, and foreign publication annual growth rates, 1993–2010.
Source: Authors' calculations.

rate of publication more rapidly than have the top tier schools. This result suggests the following hypothesis.

H1. The foreign publications of universities in Tier 2 and Tier 3 have grown faster than the two universities in Tier 1, controlling for the research inputs of R&D, university faculty, and gross provincial product per capita.

The 985 Project was initiated by the central government and directed at targeted universities, but because of the requirement of local matching funds the 985 Project also has an exhortatory effect upon the relevant provincial and local governments associated with each university. A crucial policy question regarding the value of the program is whether there are other aspects of the 985 Project that contribute to the publication outputs beyond R&D support. That is, if after having controlled for the level of R&D and faculty for each university, are there other attributes of the program that positively impacted the performance of universities? If this is the case, then we would hypothesize the following.

H2. All universities' publication rates grew faster after the implementation of 985 Project, controlling for research inputs of R&D and university faculty, and gross provincial product per capita.

There has been one other effort to evaluate the impact of such a funding program on the publications of universities applied to the case of South Korea. In his study of the Brain Korea 21 (BK21) project, Jung Shin used an interrupted time series model to test whether the BK21 project resulted in an increase in the rate of growth of publications for Korean universities once the number of Ph.D.s awarded was accounted for in the estimation (Shin, 2009). It was found that publication output did increase with a two year lag after the implementation.

4.2.1. The variables

Data on articles published in foreign journals, R&D funding, and personnel is from the Ministry of Education, Department of Universities (1993–2010). The particular variables are as follows.

lnarticles_{ij} = the dependent variable for year i and school j. The dependent variable is the natural log of university foreign publications for each year. This data includes all science and technology articles published in foreign, non-Chinese, journals.
Year_{ij} = the year of publications for school j. The years of recorded data start at 1993 and end in 2010.
$\text{R\&D}_{ij}$ = the level of R&D expended by university j in year i. The total expenditures on R&D are for each university per year, from all sources.
Personnel_{ij} = the number of science and technology personnel at university j in year i. Personnel are comprised of all scientists and engineers who are engaged in teaching, R&D activities, or science and technology service and management.[16]
GPPCap_{ij} = per capita gross provincial product in year i for the province in which school j is located. The data for all provinces, with the exception of Chongqing Province, is taken from China Statistical Yearbook (1994–2011). Data for Chongqing Province is taken from Chongqing Statistical Yearbook (2011).
Tier2_j and Tier3_j = Tier dummy variables. Tier2_j assumes a value of 1 for Tier 2 schools, and 0 otherwise. Tier3_j assumes a value of 1 for all Tier 3 schools, and 0 otherwise. Universities in Tier 1 comprise the reference category.
Project985_{ij} = Project 985 dummy variable. This is a dummy assuming a value of 1 for all years i in which the effect of 985 Project is felt on school j, and 0 otherwise.

4.2.2. The basic model

Publication growth varies greatly among universities, so it is useful to examine the determinants of this growth at the university level. One way to accomplish this would be to use dummy variables for all schools to estimate school specific intercepts and school specific slopes. Such a model, though, would have an additional 48 regression coefficients, two for each university.

Linear mixed modeling avoids this difficulty by assuming that some coefficients specific to the unit of observation are random. In this case it is assumed that the intercepts and slopes of each university are random deviations from the underlying fixed intercept and slope of the entire population. This produced a parsimonious model while allowing for differences among universities (Rabe-Hesketh and Skrondal, 2008: 141–150).

In the basic model the natural log of university foreign publications is a linear function of year of publications, along with the control variables R&D expenditures and science and technology personnel for each university. Gross provincial product per capita is also used as a control variable as this variable has been found to be significant in previous studies (Johnes and Yu, 2008; Ng and Li, 2000). This model estimates a fixed coefficient for each of these variables that applies to each of the 24 universities. In addition, it is assumed that each university's intercept is a random deviation from the population intercept, and that the slope of each university's growth rate over time is a random deviation from the population slope.[17]

The basic model is specified by Eq. (2)

$$\ln \text{articles}_{ij} = \beta_1 + \beta_2\text{Year}_{ij} + \beta_3\text{R\&D}_{ij} + \beta_4\text{Personnel}_{ij} + \beta_5\text{GPPCap}_{ij} + \gamma_{1j} + \gamma_{2j}\text{Year}_{ij} + \varepsilon_{ij} \tag{2}$$

where β_1 and β_2 = the fixed intercept of the equation and the fixed coefficient on the variable Year. γ_{1j} = the deviation of school j's intercept from the population intercept β_1. γ_{2j} = the deviation of school j's coefficient on Year from the population coefficient β_2. β_3, β_4, and β_5 = the fixed coefficients on the control variables R&D, Personnel, and GPPCap. ε_{ij} = the residual error term.

In the models to follow, the control variables R&D and Personnel were lagged by one and two years because changes in the number of personnel or amount of R&D expenditures may affect research output such as publications in later years. The impact of such inputs upon publications could be expected to lag by more than one year due to the typical time lags academic publications face (Zhang et al., 2011). To be certain, all models were run with no lag, one-year lag, and two-year lags, but this resulted in little difference in the statistical results. The unlagged results are reported here.

4.2.3. Results for the basic model (Model 1)

The results for Model 1 are shown in the first column in Table 3. This is the base model to which Models 2 and 3 are appended. The coefficients on the variables gross provincial per capita income and university R&D expenditures are positive, as expected, but are not significant. The coefficient on personnel is both significant and positively associated with foreign publications. This is also expected as

[16] Three different measures of personnel were used in this study; one measure of science and technology personnel defined as staff who are engaged in teaching, research and development together with S&T service staff, and two measures of R&D personnel defined as staff those R&D activities are more than 10% of their full-time workload. The measure of S&T personnel consistently performed better as a control variable across all models and is the basis of the results reported here.

[17] This model was run first by allowing only each university's intercept to be a random deviation from the population intercept, and then by allowing both the intercept and the slope for each university to be a random coefficient. A likelihood ratio test indicated that the model should allow both the intercept and the slope to be a random coefficient.

Table 3
Mixed linear models of university publication output.

	Model 1	Model 2	Model 3
Year	0.1146445***	0.0275787	0.1041349***
	(0.0140567)	(0.0359502)	(0.0163768)
R&D	0.0143318	0.0229565	−0.0052765
	(0.0123769)	(0.0123008)	(0.0123739)
Personnel	0.0000773***	0.0000713**	0.0000697**
	(0.0000239)	(0.0000238)	(0.0000238)
Per capita GPP	0.0000084	0.0000072	−0.0000089
	(0.0000048)	(0.0000047)	(0.0000057)
Constant	4.843793***	6.318951***	5.094633***
	(0.1600637)	(0.3993752)	(0.1668229)
Tier 2		−1.009059*	
		(0.4607182)	
Tier 3		−1.745771***	
		(0.4136641)	
Tier 2 × year interaction		0.0797111*	
		(0.0384772)	
Tier 3 × year interaction		0.0964122**	
		(0.035222)	
985 Project			−0.8321495***
			(0.1680441)
985 Project × year interaction			0.1044764***
			(0.0188867)

Standard error shown in parentheses. Significance levels as indicated.
* 0.05.
** 0.01.
*** 0.001.

the number of publications is certain to be a function of the number of potential authors.

The coefficient on year is positive and significant, and has a value of 0.114, which indicates a growth rate of 11.4%. This result is not far from the OLS result of 14.5% growth rate shown in Fig. 4. Model 1 indicates that controlling for R&D, personnel and provincial per capita income modifies the basic results obtained without these controls.

4.2.4. Model 2

In this model a dummy is used for the university tiers. After controlling for the R&D and personnel of these universities, it was hypothesized that the lower-tier schools would have a higher rate of growth in the number of foreign publications than the Tier 1 schools over the study years. To test for this, a dummy for Tier 2 and Tier 3 universities was created. Tier 2 assumes a value of 1 for Tier 2 schools and zero otherwise, and Tier 3 assumes a value of 1 for Tier 3 schools and zero otherwise. Since Tier 1 is the reference, β_1 is the intercept for Tier 1, and β_2 is the coefficient on Year for Tier 1 schools. With this we can test the rate of growth of each tier. Model 2 is specified by the following equation.

$$\begin{aligned}\ln \text{articles}_{ij} = {} & \beta_1 + \beta_2\text{Year}_{ij} + \beta_3\text{R\&D}_{ij} + \beta_4\text{Personnel}_{ij} \\ & + \beta_5\text{GPPCap}_{ij} + \gamma_{1j} + \gamma_{2j}\text{Year}_{ij} + \varepsilon_{ij} + \beta_6\text{Tier2}_j \\ & + \beta_7\text{Tier3}_j + \beta_8\text{Tier2}_j \times \text{Year}_{ij} + \beta_9\text{Tier3}_j \times \text{Year}_{ij}\end{aligned} \tag{3}$$

The first part of Eq. (3) is the base model in Eq. (2). The second part provides the additional dummy variables added to the base model.

The results of Model 2 are shown in the second column of Table 3. In this model the variables R&D and Personnel are positively associated with publications, Personnel significantly so, but Year is not significant since its coefficient only applies to Tier 1 schools. GPP per capita remains insignificant in this every other model.

The interesting result concerns the coefficients on the tier dummy variables. The coefficients on intercept shifts Tier 2 and Tier 3, as differences from the reference group Tier 1, are as expected negative and significant. The coefficients on the interaction between the tier dummies and year indicate that Tier 3 schools' publications grew more quickly than Tier 2 schools, and that Tier 2 schools grew more quickly than did Tier 1, the reference case, once the factors of university R&D and personnel were taken into account. This result is significant for the Tier 2 × Year interaction at the .05 level, and for the Tier 3 × Year interaction at the .01 level, providing support for H1.

4.2.5. Model 3

In this model the second hypothesis discussed above is tested by using a dummy that assumes a value of zero for years before the impact of 985 Project, and assumes a value of 1 for the years when it is expected to have made an impact. This dummy is applied to each university's intercept and slope as an interaction term. The 985 Project dummy tests whether or not the slope, or rate of growth in publications, for all universities increased after 985 Project was implemented after accounting for the research inputs of R&D, university personnel, and gross provincial product per capita.

The model is specified in Eq. (4) below.

$$\begin{aligned}\ln \text{articles}_{ij} = {} & \beta_1 + \beta_2\text{Year}_{ij} + \beta_3\text{R\&D}_{ij} + \beta_4\text{Personnel}_{ij} \\ & + \beta_5\text{GPPCap}_{ij} + \gamma_{1j} + \gamma_{2j}\text{Year}_{ij} + \varepsilon_{ij} + \beta_6\text{Project985}_i \\ & + \beta_7\text{Project985}_i \times \text{Year}_{ij}\end{aligned} \tag{4}$$

The second part of (4) provides the additions of this model to the base model in (2). The 985 Project dummy assumes a value of 1 in the year a given university was included into Project 985. It was thought that the impact of the project may not be felt for some time after its start. For example, in a study of the Korean BK21 project Shin (2009: 676) used a two year lag to measure this project's impact. All of these models were run under one year, two year, and no lag assumptions for the impact of 985 Project, with little difference in results. The unlagged results are reported here.

The results of Model 3 are shown in the third column of Table 3. In this model, like Model 1, the coefficients on Year and Personnel are significant and positively associated with university publications. More revealing is that the coefficient on the interaction between the 985 Project dummy and year is positive and highly significant, indicating that indeed the rate of growth of publications increased after the implementation of the program.

These results lend support to the second hypothesis, H2, that after the implementation of 985 Project, university publications, after controlling for research inputs of R&D, university faculty, and provincial per capita income, grew more quickly.

5. Discussion

As with many government officials around the world during the last two decades, Chinese government officials have repeatedly stated their commitment to improving national R&D capabilities, but in the case of China these avowals have been proven by action. The sheer volume and rate of expansion of government investment suggests a remarkable commitment to improvement of R&D capability as measured by international publications. While it is not possible to definitively state that China will be capable of building top-flight research universities to rival the Western or even Japanese flagship universities, the Chinese effort appears to still be at an early stage. It would be a mistake to underestimate the depth and potential of this commitment.

In China's National Medium- and Long-Term Sci-Tech Development Planning Program (2006–2020) it was proposed, as a strategic goal, that China develop into an innovation-oriented country by 2020 with a ratio of investment in R&D to GDP increasing from the current 1.7% to over 2.5% in 2020.[18] The goal is to have China among the Global Top 5 in terms of patent applications and citations to scholarly articles. The Chinese government has encouraged firms to perform an increasingly large percentage of the total R&D. In many respects, this goal has been successful as the firm contribution to total R&D increased from 44% of national R&D in 1997 to 73% in 2009.[19]

The data suggests that the 985 Project in conjunction with other policies has led to an increased volume of Chinese university-authored papers in foreign language journals and that the change has been quite dramatic. The policy appears to have been particularly beneficial to second and third-tier universities. Some second-tier universities, particularly Zhejiang University, and a few third-tier universities such as Sun Yat-sen University and Shandong University, have shown marked and sustained publication rate increases, which if they continue may, in terms of publications, erode the current tier structure. This would be a particularly interesting development because in contrast to other East Asian nations, where the hierarchy of universities has remained largely unchanged, in China it is possible that there may be a reordering of the hierarchy.

There are of course limitations to a study of this type, which in turn suggests possible directions of further research. First, it should be noted that because increasing publications in foreign journals is an objective of Chinese education policy, this data is an appropriate measure of such policies as the 985 Project. There are of course substantial quality differences among foreign journals, so a better measure of university research outcomes would be based on publications in journals ranked by quality or scholarly impact. As one reviewer pointed out, in addition, it would be very revealing if one knew the extent to which international collaboration contributed to the growth of foreign publications.

Second, a clearer appreciation of the impact of the 985 Project could be obtained if one had a measure of increased R&D funding for each university as a result of this program per year.[20] Addressing both of these limitations suggest useful directions for future research.

While this paper cannot answer the question of the quality of the outpouring of papers, the Academic Ranking of World Universities (ARWU) provides some insight into "quality" with two data categories: highly cited researchers and articles published in *Nature* and *Science*. Chinese universities do not, as yet, have any highly cited researchers, but have made some headway in increasing the number of *Nature* and *Science* articles. The time series for the ARWU data is from 2003 through 2010, and Tsinghua and Beijing Universities have been the leaders among all Chinese universities during the entire period, but some second-tier universities could match their performance in the near future. The data suggest that not only has there been quantitative improvement, but also there has been some measure of qualitative improvement. And yet, in terms of the goals articulated by the government, success will only be achieved if Chinese universities can also improve in terms of quality indicators.

From an international perspective the top Chinese universities compare well with other universities in the region as shown in Table 4 with regard to articles published in *Science* and *Nature*.

There are concrete obstacles to improving the quality of the venues and increasing citations to Chinese authored articles. The first of these, namely the fact that most SCI journals are in English, has particularly plagued East Asians. In part this may be addressed as younger, internationally trained researchers replace the current generation of university professors. Also, a learning-by-doing dynamic may be occurring as the peer-review process itself teaches Chinese scholars. There are other obstacles. Garnering greater numbers of citations is not simply a matter of publication, but also of belonging to the correct network (Gmür, 2003; Zuccala, 2006) or as Merton (1967) put it, the "invisible college" (see also Crane, 1969). The ability to publish and to garner citations is also affected by the communities to which journal editors belong, and, here again, Chinese and other non-Western scholars may be at a disadvantage.

One of the puzzles that our research uncovers but cannot answer is how Chinese professors were able to increase their publication rates so dramatically. Data that we could not secure by university was what in aggregate was a massive increase in the number of Ph.D. degrees being awarded and the number of postdoctoral personnel employed (see Fig. 8). In contrast, the number of university professors increased relatively more slowly.[21] This increase in research personnel could be expected to increase the number of publications on a per faculty basis. In China, graduate students are important in the production of publications. For example, in the case of Shanghai Jiaotong University (cited in Liu, 2007: 56) "more than half of the first authors of cited articles from [the university] are graduate students." This is driven by the largely uncodified but nonetheless well-recognized requirement at most universities that Ph.D. candidates publish one or two papers prior to receiving their degree. To illustrate, to graduate from Tsinghua University Ph.D. candidates in Physics, Chemistry, Mathematics, Biology, Material and Dynamics must publish four papers in core journals, two of which must be SCI journals. Ph.D. students in the School of Information Science and Technology must publish one paper in an SCI journal or two in Engineering Index journals (Basic Requirement for Graduate Students During their Study at Tsinghua University, made by Degree Commission in 2002). Given Tsinghua's role as a

18 According to Tsou (1998), Chinese policy makers consider science and technology so similar that they have merged the two terms into the single term "sci-tech."

19 In some measure, this was accomplished by the conversion in 2001 of 923 research institutes into enterprises, thereby "privatizing" their R&D expenditures.

20 It is not known if such data exists. There is specific Project 985 R&D expenditure data for Beijing University and Tsinghua University for the years 1999–2001, but all other data is aggregated by years and by groups of universities.

21 Source of this data is Ministry of Education (1997–2009).

Table 4
ARWU score on *Nature* and *Science* publications.

	2003	2004	2005	2006	2007	2008	2009	2010
Tsinghua University	10.6	8.8	9.9	10.9	11.6	9.4	9.2	11.8
Beijing University	11.1	10.0	11.3	13.0	11.4	11.7	11.4	13.5
National U. of Singapore	13.9	12.7	13.8	13.7	12.9	13.0	13.4	14.6
Seoul National University	15.7	15.4	14.6	14.3	13.5	11.5	12.6	13.1
Chinese U. of Hong Kong	4.5	4.3	5.1	5.0	4.0	6.7	6.2	6.1
India Institute of Science	10.8	11.5	9.8	8.4	8.7	8.2	6.4	6.3

Source: Academic Ranking of World Universities, various years. http://www.arwu.org/.

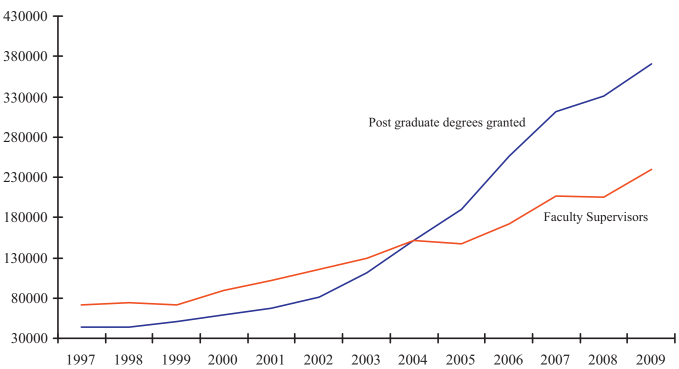

Fig. 8. Number of postgraduate degrees granted and faculty supervisors for all Chinese universities, 1997–2009.

Source: Educational Statistics Yearbook of China, 1997–2009 (various years). Ministry of Education, Department of Development & Planning, P.R. China. 1997–2009 (various years). Educational Statistics Yearbook of China. Beijing. China.

trend-setter, the other 985 Project universities are likely to have similar requirements.

We were unable to find a consistent measure of Ph.D. degrees awarded by each university over time. It is likely that this missing variable, if included in our analysis, would prove to be positively and significantly associated with the output of foreign publications. Given the importance of Ph.D. students to the production of publishable research in China, it is plausible that the hypothesized increase in publications following the 985 Project could be due in part to this significant increase in doctoral students in China.

6. Conclusion

The 985 Project is the most dramatic of a series of policies implemented by the government to move selected Chinese universities to the global scientific and technological frontier. Our results suggest that the lower-tier universities may have benefited more than did the first-tier universities. In policy terms, this may be most interesting because it suggests that targeted investment combined with incentives for performance can result in universities making rapid and significant improvements in their global status. In the case of publications in quantitative terms, Chinese policies have achieved notable success. In certain fields, such as nanotechnology, Chinese public-sector research is recognized as a contributor to the global scientific community (Zhou and Leydesdorff, 2006). Still, there is a lingering question of whether increasing quantity will produce recognition and quality.

It is likely that ultimate recognition of Chinese success will only come as China becomes more integrated into the global community of scholars. In some measure, this may be achieved by continued investment in indigenous resources, continuing the policy of attracting Chinese nationals from abroad, but it may also be that the Singaporean route of attracting established non-Chinese scholars for short-term stays will be needed. Finally, at this point English remains the scientific and technological language of choice and it is likely that this will remain a barrier to Chinese scholars.

While our data suggests that massive investment in university research appears to have benefited second- and third-tier universities more than those in the first tier, all of the 985 universities are among the best in China so this increasing support may be creating greater competition for and among the elite universities, an outcome that many nations would find desirable. Further, the 985 Project could result in greater competition that might lead to the creation of a more vibrant national university research ecosystem whose outcome might more resemble that of the U.S. than that of smaller nations. The performance of Zhejiang and Nanjing Universities, which always were quite highly rated, suggests that the current hierarchy may be open to challenge. Because provincial and city governments also can devote funds to university research, it might be possible for them to leverage national funding by expending even greater funds on their universities. For provinces considering this strategy, the University of California system with its multiple campuses might be an interesting model.

Despite the fact that Chinese scholars have not become highly cited or won Nobel prizes,[22] their increasing publication in international venues is a clear sign that Chinese absorptive capacity for scientific and technological advances abroad is improving significantly (Cohen and Levinthal, 1989, 1990). While this is not the stated goal of the Chinese government, this outcome would be rather close to the path that other East Asian Tigers have followed, beginning with Japan and then followed by Taiwan, Korea, Hong Kong and Singapore, yet there is evidence that China is accomplishing this more rapidly than these earlier pioneers.

Acknowledgements

Han Zhang thanks the Key Programme of National Science Foundation of China (NSFC) for funding the research under NSFC Award No. 71033001, and all three authors greatly appreciate the valuable suggestions they received from two anonymous reviewers.

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[22] See, Cao (2004) for the Chinese fixation on winning a Nobel Prize in science.

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