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Intellectual Returnees as Drivers of Indigenous Innovation: Evidence from the Chinese Photovoltaic Industry

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Abstract

This paper offers new evidence on the link between indigenous innovation and intellectual returnees by estimating the relationship between firm-level patenting and the presence of corporate leaders who have studied or trained in an advanced country. Our research approach requires the combination of data from three distinct sources: the Chinese industrial census, international and domestic patent records, and firm leadership biographical information. Using nonlinear methods appropriate to count data, we test whether the presence of intellectual returnees in leadership positions within the firm leads to a higher likelihood of patenting. We find robust evidence that returnees do influence firm patenting activity and also provide some benefits for innovating activity of neighboring firms via inter-firm spillovers. We find no tendency for firms with greater export intensity to patent more, nor do we find differences across firms based on age or size. Controlling for expenditures on R&D activity, we still find that firms with intellectual returnees in leadership roles have more patents.

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Abstract: This paper offers new evidence on the link between indigenous innovation and intellectual returnees by estimating the relationship between firm-level patenting and the presence of corporate leaders who have studied or trained in an advanced country. Our research approach requires the combination of data from three distinct sources: the Chinese industrial census, international and domestic patent records, and firm leadership biographical information. Using nonlinear methods appropriate to count data, we test whether the presence of intellectual returnees in leadership positions within the firm leads to a higher likelihood of patenting. We find robust evidence that returnees do influence firm patenting activity and also provide some benefits for innovating activity of neighboring firms via inter-firm spillovers. We find no tendency for firms with greater export intensity to patent more, nor do we find differences across firms based on age or size. Controlling for expenditures on R&D activity, we still find that firms with intellectual returnees in leadership roles have more patents.

Key words: international technology transfer, intellectual returnees, photovoltaic, innovation, patents, China

Introduction

Innovation is seen as the driving force of productivity growth (Freeman and Soete, 1997; Freeman and Louca, 2001; Fagerberg and Verspagen, 2002). However, as shown by Breznitz and Murphree (2011) for the case of China, breakthrough innovation is not the only route to sustained growth. China has maintained steady income advances by receiving new technology from richer countries and mastering subsequent stages of innovation, a process known as “incremental innovation.”¹ This process is an obvious consequence of intensified globalization and fragmentation of production, facilitated by both trade and investment flows across national borders.

Various channels by which cross-border flows facilitate international technology transfer have been identified.² Empirical studies have identified significant channels through international trade (e.g Keller, 2010), foreign direct investment (e.g. Veugelers and Cassiman, 2004; Kemeny, 2010), and joint R&D ventures (e.g Zhou, et al., 2012)). Other scholars note the importance of supply chains to technology transfer, and especially to indigenous innovation. Xu and Sheng (2012) use firm-level evidence from China to argue that positive spillovers from FDI arise from forward linkages, that is, from access to superior intermediate inputs or capital equipment. Puga and Trefler (2010) expand the idea of forward linkages when they argue that the movement of new products from a developed to developing countries induces incremental innovation as the production process is refined and standardized in the low wage setting. This process of indigenous innovation allows low wage countries to export increasingly sophisticated new goods, thereby reducing the length of the product cycle and rapidly shifting world trade patterns.³

Recently, attention has shifted to indigenous innovation sparked by “intellectual returnees,” defined as skilled persons who study or work in an advanced economy and subsequently return to their country of origin to engage in technology-related activities (Mountford, 1997; Kapur and McHale, 2005; Zucker and Darby, 2007). Returnees may

¹ Puga and Trefler (2010) attribute coinage of the term “incremental innovation” to Rosenberg (1982) and describe this form of invention as the “unsung hero of modern economic growth.”

² Keller (2004, 2008) provides comprehensive surveys of the channels of international technology diffusion.

³ Puga and Trefler (2010) provide a formal model of this process and supporting evidence of incremental innovation in low wage countries by combining data on the location of first production for innovative goods with data on patents by low wage country inventors for U.S. corporations.

offer their home countries human and venture capital, familiarity with systems developed by multinational firms, and valuable connections and cultural links to their host countries (Wang, Zweig, and Lin, 2011). Despite the prevalence of individual success stories from intellectual returnees in India and China, there is limited systematic evidence on the role played by cross-border migration of skilled workers to innovation within their country of origin.

This paper offers new evidence on the link between indigenous innovation and intellectual returnees by estimating the relationship between firm-level patenting and the presence of corporate leaders who have studied or trained in an advanced country. Our research approach requires the combination of data from three distinct sources. First, we use industrial census data to create a panel of more than 800 firms in the Chinese photovoltaic (PV) industry over the period 1998 to 2008. Secondly, we search Chinese and international patent office records to link each PV firm to its patenting activity. Lastly, we use firm, industry, and media reports to find the tertiary education and job experience of each firm's chief executive officer and board members in each year, identifying those who have studied or trained overseas.

Using nonlinear methods appropriate to count data, we test whether the presence of intellectual returnees in leadership positions within the firm leads to a higher likelihood of patenting. We find robust evidence that returnees do influence firm patenting activity and also provide some benefits for innovating activity of neighboring firms via inter-firm spillovers. We find no tendency for firms with greater export intensity to patent more, nor do we find differences across firms based on age or size. Controlling for expenditures on R&D activity, we still find that firms with intellectual returnees in leadership roles have more patents.

Previous research has emphasized the importance of domestic absorptive capacity necessary for international technology transfer, as well as the possible role for intellectual returnees in this process. Fu, Pietrobelli, and Soete (2011) provide evidence from emerging economies that international technological diffusion can only occur with parallel indigenous efforts. Fu and Gong (2011) investigate this process in the specific case of China and find that indigenous R&D at the industry level is the major driver of technology upgrading for domestic firms. Looking specifically at the Chinese PV

industry, de la Tour et al. (2011) argue that intellectual returnees played a major role in bringing foreign technology to China to exploit its comparatively cheap labor and energy. Our analysis builds on these efforts by directly linking Chinese PV firms to their patent filings and testing the relationship between these innovative activities and foreign training of the firm's leadership. Thus, our work expands upon prior literature by drawing a direct link between indigenous innovation and intellectual returnees.

1. China's photovoltaic industry and the patent explosion

The Chinese PV industry, which has developed from virtually nonexistent to the world's third largest in less than a decade, is well suited to a study of returnees and incremental innovation. First, products along the silicon-based solar supply chain are highly standardized, eliminating complexity introduced by differences in product quality. Secondly, the industry relies on production technologies initially developed in industrialized countries, implying an initial transfer of advanced knowledge and equipment to China. Thirdly, and perhaps most importantly, significant complementary adaptation is needed all along the chain, and especially in upstream stages requiring advanced technologies and specific skills. Using detailed knowledge of the PV industry and extensive field interviews in China, de la Tour et al. (2011) conclude that, "a major part of the technology concerns the operation of manufacturing processes, which mainly consists of know-how. In the context, the manufacturing experience of skilled employees is a key asset."⁴ Lastly, there is evidence of a significant number of intellectual returnees in leadership roles in the industry (de la Tour et al., 2011; Luo and Yu, 2012). For these reasons, the PV industry is fertile ground for testing whether incremental innovation can be fueled by leaders familiar with overseas technologies and operations.

1.1 Emergence of China's PV industry and intellectual returnees

China's emergence as a major producer and exporter of photovoltaic equipment occurred rapidly. As seen in Figure 1, worldwide installation of new solar power

⁴ de la Tour et al. (2011) use industry directories and field interviews to support their claim that Chinese producers acquired the skills and technology necessary to compete in this newly emergent sector through two main channels: imported capital equipment and the return of skilled individuals. They find a very limited role for technology transfer through multinational activity and none for licensing.

generating capacity grew from a very small base in 2001 to 16,000 megawatts by 2010. Within a decade, hundreds of Chinese PV firms participated in all segments of the PV supply chain, from silicon purification and wafer production to cell production and module assembly, leading to rapid declines in the installation price of solar equipment worldwide. Today, many of the largest and most visible firms in the industry, including Suntech, Trina, JingAo, and Yingli, are Chinese enterprises.⁵

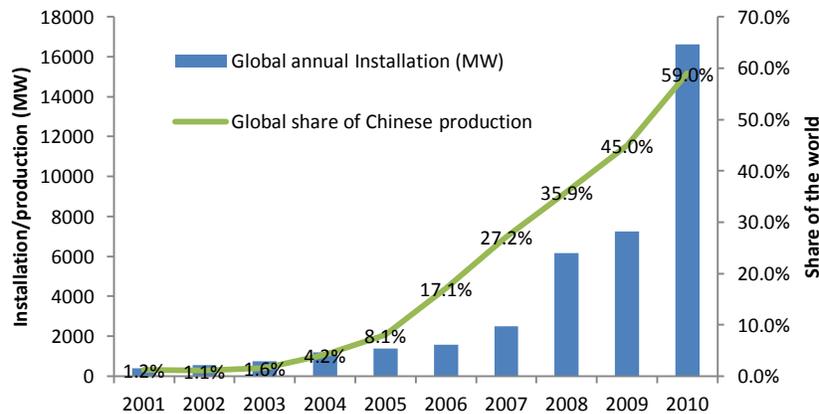


Figure 1 Chinese photovoltaic industry development trend (Source: (EPIA, 2011))

While exporting more than 95% of its production, China’s share of global PV production rose from 1% in 2009 to 59% by 2010.⁶ It remains the world leader in cell production and module assembly, segments with relatively low technological barriers to entry and low industrial concentration. With strong support from the government, Chinese firms have rapidly increased their presence in upstream activities. Their capacity to purify silicon and produce ingots and wafers, both of which require technologically advanced production processes, has allowed them to increase market share in these segments (de la Tour et al., 2011).

China’s rapid entry into the global PV market has led to considerable trade friction. After failing to obtain significant countervailing duties on solar panel equipment imports from China, in 2012 the United State imposed anti-dumping duties of approximately 35% on billions of dollars of solar products to protect domestic manufacturers from lower-

⁵ A global supply glut and heavy debt pushed Suntech Power Co. into Chinese bankruptcy court in March 2013. Suntech had been the world’s largest manufacturer of solar panels but now faces an uncertain future (Ma and Glazer, 2013).

⁶ Recently, China has moved strongly to increase domestic installed capacity. China was the top non-European PV market in 2011, with 2.2 GW installed, followed by USA with 1.9 GW (EPIA, 2012).

priced imports. The European Union will decide by June 2013 whether to impose tariffs of up to 60% on imports worth five times as much as the American volume. The EU has also initiated investigation into claims of unfair trade practices based on alleged Chinese government subsidies to solar panel makers.⁷

The reasons for China's export success and apparent cost advantage are complex and beyond the scope of this paper.⁸ However, extensive data collection and field research by de la Tour et al. (2011) identify the importance of international technology transfer as the driver of China's success. They argue that successful entry into each segment of PV production requires state-of-the-art production technology. While turnkey operations can be purchased in the downstream cell and module assembly segments, equipment suppliers are scarce in the upstream segments of silicon purification and wafer production. Particularly in these more advanced segments and for continuing adaptive innovation in downstream segments, de la Tour et al. (2011) highlight the importance of skills and indigenous adaptation as key to China's success.

During China's PV industry development process, intellectual returnees played a crucial role in mastering the technology and techniques needed to produce for export. Pioneers in the industry are the well known "three returnees of China's photovoltaic," Huaijin Yang, Zhengrong Shi, and Jianhua Zhao. These three men, originally from Jiangsu province, studied photovoltaic technology in Australia in the 1990s, and then returned to China with advanced technology and foreign capital to start firms using China's relatively low-wage skilled labor force.

Besides the famous "three returnees," there are hundreds of returnees in China's PV sector. The importance of returnees to the industry is a central finding from field interviews carried out by Luo and Yu (2012) and by de la Tour et al. (2011). Not only the return of foreign trained pioneers but a continuing flow of talent back to China is suggested by these sources. Exact counts are not available, but industry sources report most large firms engage in aggressive recruiting of ex-pat executives with overseas training.

⁷ See James Kanter, European Importers Defend Chinese in Anti-Dumping Case, The New York Times, February 19, 2013, <http://www.nytimes.com/2013/02/20/business/global/european-solar-importers-defend-chinese-in-anti-dumping-case.html>.

⁸ Besides concerns about government subsidies and export pricing behavior, observers often point to scale economies due to the large size of almost all aspects of PV manufacturing in China.

1.2 A patent explosion in Chinese photovoltaics

Due partly by increased official attention to patenting, over the past decade there has been a Chinese patent “explosion” (Hu and Jefferson, 2009). Analysis by Eberhardt, Helmers, and Yu (2012) found that the number of domestic filings with the Chinese patent office increased at an average annual rate of 35% during the period 1999-2006. However, their examination of domestic and international patent applications by manufacturing firms registered in China found that an overwhelming share were from a handful of companies in the ICT equipment sector, especially for those also filed with the U. S. Patent Office.⁹ Moreover, they find that most innovation is done by large, relatively young firms that are more R&D-intensive and export oriented than their peers.

Our investigation of patenting by Chinese PV firms also finds a patent “explosion” in recent years.¹⁰ To document these firms’ innovative activity, we search and extract all patents records for Chinese PV firms filed in China, using records of the State Intellectual Property Office (SIPO), and with international patents office, using records from the Derwent World Patents Index (DWPI).¹¹ As further checks to ensure completeness, we search information for Chinese patents available from the China National Knowledge Infrastructure (CNKI) and for worldwide patents using Delphion.¹²

These methods yield a total of 3508 patent applications from 290 Chinese PV firms through 2011. Patent applications increased from 14 in 2000 to 973 in 2010, implying an annual growth rate of 68%. China’s patents have also increased relative to worldwide levels: taking the main PV technology, crystalline silicon solar, as an example, patents in this technology increased explosively from 2007-2011, raising China’s global share of patents from 2.9% to 17.6%.

⁹ Because of the costs of filing abroad, along with a one-year waiting period that gives inventors additional time to gauge their invention’s value, only the most valuable inventions are filed in multiple countries. Because of this, researchers such as Lanjouw and Schankerman (2004) have used data on patent families as proxies for the quality of individual patents. Lanjouw and Mody (1996) use such data to show that environmental technologies patented by developed country firms are more general than similar inventions from developing countries, as the developed country inventions are protected in more countries.

¹⁰As explained below, we use China’s Annual Survey of Industrial Firms to identify all firms operating in any segment of the PV supply chain. A comprehensive search finds 806 photovoltaic firms, but many of these have very limited production.

¹¹The Derwent World Patents Index (DWPI) is a comprehensive database of enhanced patent information, covering more than 20.7 million inventions from 47 different international patent-issuing authorities.

¹² A sub-dataset of CNKI provides all updated patents information of SIPO, and Delphion provides worldwide detailed worldwide patent information. Follows are the website links: <http://dbpub.cnki.net/Grid2008/Dbpub/Brief.aspx?ID=SCPD&subBase=all>; <http://www.delphion.com/>.

As many researchers have noted, not all patenting activity signals the same level of innovation. Fortunately, patent documents contain details that make it possible to sort them into categories that reflect the quality of the innovation.¹³ Specifically, Chinese patent law allows for three types of patents - invention, utility, and design - and the type is listed in the patent record. Invention patents refer to new technical solutions relating to a product or process. They provide 20 years of protection and are analogous to patents in industrialized economies. Utility patents refer to minor improvements to existing technology. They provide only 10 years of protection and apply to any new technical solution relating to the shape or structure of a product. Design patents cover the aesthetic design of a product and also provide just 10 years of protection.¹⁴

Detailed scrutiny of each of the 3508 patent records suggests that much of this innovative activity represents the “incremental innovation” highlighted by Puga and Trefler (2010) as necessary to move production of new technologies to developing countries. As illustrated in Figure 2, about two-thirds of patent applications from Chinese PV firms represent process innovations: improved devices, tools, or methods that enhance production efficiency or product quality. While only about one-third of patents represent inventions, the number of these more valuable innovations increases steadily over the decade. These trends are consistent with an industry that uses existing technology from foreign countries and initially directs research efforts mainly to adaptation and “minor” innovation rather than basic research. As the industry has expanded, however, it seems that more effort is directed to fundamental research resulting in more invention patents.

Figure 2 also shows the distribution of patent counts among those firms with patents. Compared to other industries in China (Eberhardt et al., 2012), patenting is more widespread in the PV industry. We find that the average patent count among all firms is 4.35, with an average of 12.1 among those with one or more patents.

Table 1 illustrates the top patenting PV firms in China: Suntech, Trina, Shanghai Solar, CEEG, and Yingli. These firms are domestic, either private or state-owned

¹³ Because of the detail available on patent documents, patents are widely used in studies of environmental innovation (see Popp et al. 2010 for a review).

¹⁴ Descriptions of the various patent types come from the State Intellectual Property Office of P.R.C, http://www.sipo.gov.cn/zsjz/zhzs/200804/t20080418_383771.html, and the Embassy of United States, <http://beijing.usembassy-china.org.cn/iprpatent.html>.

enterprises.¹⁵ In addition to their patent counts, the table shows that with the notable exception of Suntech, most firms have more utility and design patents than invention patents and hold few international patents. For all firms, the majority of patents represent improvement in production rather than process technology.

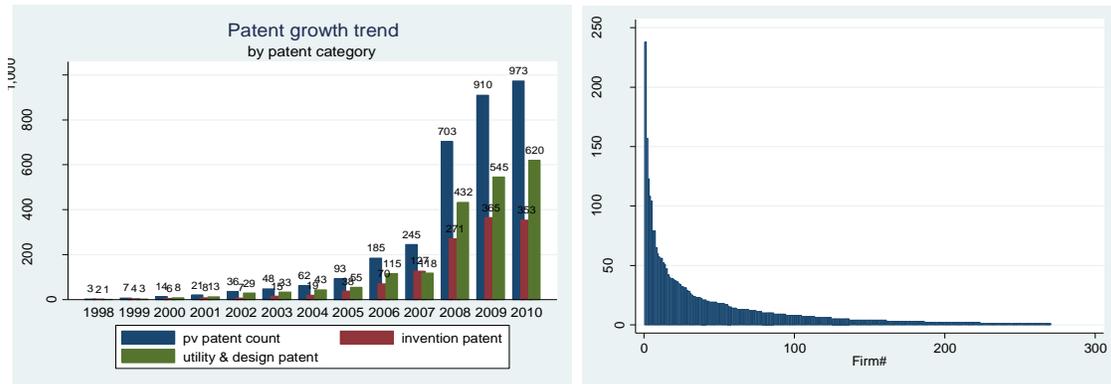


Figure 2 Chinese photovoltaic patents growth and distribution (Source: (DWPI, 2012))

Table 1 Chinese top patenting photovoltaic firms (Source: DWPI)

| Firms | Total patent | Invention patent | Utility & Design patent | Production technology | Process technology | International patent | Notes |
|----------------|--------------|------------------|-------------------------|-----------------------|--------------------|----------------------|---------|
| Suntech | 157 | 98 | 59 | 59.9% | 40.1% | 70 | Private |
| Trina | 123 | 47 | 76 | 66.7% | 33.3% | 7 | Private |
| Shanghai Solar | 104 | 45 | 59 | 60.6% | 39.4% | 0 | State |
| CEEG | 79 | 30 | 49 | 73.4% | 26.6% | 0 | State |
| Yingli | 65 | 30 | 35 | 69.2% | 30.8% | 3 | Private |

2. Research design: intellectual returns and innovation capacity

Our basic approach is to regress a firm’s patent count on an indicator for the presence of an intellectual returnee among a firm’s leadership. We control for a variety of other factors that determine the firm’s innovative activity. We identify the effects of international experience using both differences between and within firms, as we discuss in greater detail in section 5.

2.1 Patents counts as an indicator of technology innovation

We use patents as a measure of each firm’s innovation efforts. Patents provide a temporary legal monopoly to use an innovation in a specific market. In contrast to data on R&D spending, which has only limited availability and is subject to numerous

¹⁵ Of the top nine PV companies in China in 2008 and 2009, de la Tour et al. (2011) find that only three have investment links with foreign companies and these are late arrivals, following the Chinese pioneers.

measurement problems, patents are publicly available documents, with a long history even in some developing countries (Nagaoka and Motohashi et al., 2010). While patents are an output of the innovation process, economists have found that patents provide a good indicator of innovation activity (see, e.g., Griliches 1990). Moreover, due to the detail available on patent documents, patents are widely used in studies of environmental innovation (see Popp et al. 2010 for a review).

Nonetheless, when working with patent data, it is important to be aware of their limitations. The existing literature on the benefits and drawbacks of using patent data is quite large.¹⁶ While the tendency to patent varies across industry and by country, focusing on a single industry in a single country mitigates these concerns in our study. Also, as noted earlier, Chinese patent data enable us to address differences in the quality of patented inventions, using the categories of invention, utility, and design described in section 2.

2.2 Determinants of a firm's technology innovation

Many internal and external factors determine a firm's technology innovation activities. Our study focuses on the role of international technology transfers resulting from international personnel movement. Returnees may be an important technology transfer channel, but their impact is not well studied because international personnel movement is typically conceived as a "brain drain" through which talent is transferred from developing nations to the developed world (Fagerberg et al., 2010). Part of the explanation for this gap in the literature may also be the difficulty of obtaining data on returning intellectuals and their innovative activities. With the recent emergence of indigenous innovation and large existing stock of overseas talent, however, China now presents a unique opportunity to study the possible impact of intellectual returnees.

Returned talent can improve a firm's technology innovation through a variety of channels. First, intellectual returnees generally have better professional training than domestic peers and thus will increase the number of patents a firm holds by providing greater human capital to the enterprise. Some returnees possess knowledge of advanced technologies from employment in developed country firms and may even own patents pertaining to these technologies. Bringing back such knowledge can improve the human

¹⁶ Griliches (1990) provides a useful survey.

capital of domestic firms (Kapur and McHale, 2005). Secondly, returnees often are recruited back to China at salaries higher than those paid to domestic workers and, thus, are likely to be placed in leadership roles within the firm. A leadership position may give an intellectual returnee the platform by which to influence the firm's innovative and patenting activity. For these reasons, we expect that the presence of intellectual returnees in a leadership position to raise a firm's patenting activity.

To ensure that we isolate the effect of returnees within the firm, we must control for other factors that also influence its patenting behavior. One channel may be through talent located in neighboring firms that raises a firm's innovative potential through formal or informal interactions or even personnel movement among firms (Zucker and Darby, 2007). Using a sample of over 1300 firms located in China's largest science park, Filatotchev et al. (2011) find evidence in support of significant positive spillovers from returnees to other local high-tech firms. Therefore, in testing for a positive relationship between a firm's returnees and its patenting activity, we control for the presence of returnees as leaders of neighboring firms.

Additional spillovers may come from external scale economies or co-location near major universities. External economies would be evidenced by industry agglomeration, which may affect firms' innovation by facilitating knowledge spillovers, through input-output linkage and by labor market sharing (Ellison, Glaeser, and Kerr, 2010). Major universities or research institutes can also be the source of innovative capacity, especially where enterprise-university linkages are strong (Edquist, 2004).

The literature on firm-level innovation suggests other channels of international technology transfer, such as international trade and FDI, that also contribute to firms' technology innovation (Lin and Zhang, 2005; Keller, 2010). While there is very little foreign investment in the PV sector, there are significant export flows and keeping up with competition in export markets may induce more innovative activity. Therefore, we also control for firm export intensity in our empirical implementation.

The literature also suggests several firm characteristics that are important determinants of innovative performance (Cohen (2010) provides a review). Examples include firm size, age, and market share. We include these as controls in the model that follows. Lastly, we include year fixed effects to control for patenting shocks common

across firms in a given year, such as those due to changes in government policy, bank lending behavior, or the business cycle.

2.3 Empirical implementation

Our data set, described in more detail in section 4, is an unbalanced panel of 806 firms over the time period 1998-2008. Our dependent variable is the number of patent applications filed by firm i in year t , where t is the application year of the patent. The basic empirical model is:

$$\text{Patent}_{i,t} = f(\text{IntlExper_Leader}_{i,t}, \text{IntlExper_Exec}_{i,t}, \ln(\text{IntlExper_Spillover}_{i,t}), \ln(\text{IndustryCluster}_{i,t}), \ln(\text{UnivDist}_{i,t}), \mathbf{X}_{i,t}, \text{year}_t) \quad (1)$$

All continuous variables are included in logarithmic form in the model so that we can interpret coefficients as elasticities.

We include two indicators of the international experience of a firm's leaders. $\text{IntlExper_Leader}_{i,t}$ is a dummy variable equal to one if the firm's president or CEO has international experience. $\text{IntlExper_Exec}_{i,t}$ is a dummy variable equal to one if one or more of the firm's executives have international experience. In both cases, international experience means that a certificated overseas education or foreign working experience can be found on the resume of the firm's leader or executives. The most common international experience is overseas education, which accounts for 80% of overall international experience in our dataset.

To investigate whether spillovers from the presence of returnees in neighboring firms operate in the PV industry, we create a firm-level measure of proximity to firms lead by intellectual returnees. This variable, $\text{IntlExper_Spillover}_{i,t}$, sums over the international experience of all other firms in year t , placing more weight on the international experience of nearby firms using the formula:

$$\text{IntlExper_Spillover}_{i,t} = \sum_{j \neq i} \frac{I_{j,t}}{d_{i,j}}$$

Here, $I_{j,t}$ is a dummy variable equal to one if firm j 's leader in year t has international experience, and $d_{i,j}$ represents the distance between firms i and j . We measure the

distance between firms using county centroids.¹⁷

The inclusion of $IndustryCluster_{i,t}$ tests for the effects of industry agglomeration. We measure industry clustering as the sum of other PV firms' output discounted by distance. Defining $v_{j,t}$ as output for firm j in year t and $d_{i,j}$ as the distance between firms i and j , we calculate industry cluster as:

$$IndustryCluster_{i,t} = \sum_{j \neq i} \frac{v_{j,t}}{d_{i,j}}$$

We use $UnivDist_{i,t}$ to examine the potential benefits of locating near a research university. This variable measures the distance to the nearest top university (or public research institute), defined as:

$$UnivDist_{i,t} = \text{Min}\{D_{i,u}, u = 1, \dots, 25\}, \quad i = 1, \dots, N$$

Here $D_{i,u}$ is the distance between firm i and each of the top 25 universities in China, u .¹⁸ N represents the total number of firms in our sample.

$\mathbf{X}_{i,t}$ is a matrix of firm characteristics used as control variables. Our controls for firm characteristics include a measure of market power, defined as the share of total PV industry sales for firm i in year t , the export share of total sales for firm i in year t , the age of each firm at time t , and the size of the firm measured as the number of employees.

We also include a series of dummy variables indicating the nature of firm i 's production: upstream (silicon purification), midstream (silicon ingot/wafer/ cells), downstream (panels), or comprehensive firms that fully or partially integrated, and thus produce some upstream and downstream products. We control for ownership with a series of dummy variables for ownership type: state, foreign, HMT (Hong Kong, Macau and Taiwan), collective, or private enterprise. Lastly, we include a series of year dummies to control for changes over time affecting the entire industry, such as changes in

¹⁷ Since we know the county in which each firm is located, we calculate the distance between firms in the same county using the common formula $\left(\frac{2}{3} \sqrt{\text{area}/\pi}\right)^\delta$, where area refers to the county's area.

¹⁸ The top 25 universities and public research institutes in China are as follows: Tsinghua University, Nanjing University, Peking University, Shanghai Jiao Tong University, University of Science and Technology of China, Zhejiang University, Huazhong University of Science and Technology, Shandong University, Sichuan University, Sun Yat-sen University, Beijing University of Aeronautics and Astronautics, Dalian University of Technology, Harbin Institute of Technology, Jilin University, Southeast University, Wuhan University, Xian Jiao Tong University; and three institutes of China Academy School. University rankings are taken from <http://www.shanghairanking.com/Country2011Main.jsp?param=China>.

environmental or patent policy.

3. Data on Firm Characteristics, Patent Applications, and Leadership Experience

Our research design requires the combination of firm-level data, which allows us to identify PV firms and their characteristics, with patents record for these firms over the period 1998 to 2008. It also requires us to collect information on the identity of firm CEOs and leading personnel and whether or not they have relevant international experience.

3.1 Photovoltaic firm characteristics

We identify photovoltaic firms from 1998 to 2008 using the Annual Survey of Industrial Firms (ASIF) provided by China's National Bureau of Statistics. From this source, we obtain information on a total of 806 unique firms listing a PV product among their top three activities. The ASIF is a universal database covering all major industrial firms, including all state owned enterprises and non-state firms with annual turnover above 5 million RMB (about US \$800,000 in sales). This industrial census provides basic information such as corporate identity, location, and establishing year, and firm operating information including output value, sales, intermediate input, value added and tax, employment, assets and liabilities, and other financial data.

Photovoltaics is an emerging technology and there are no unique industry code specifying PV firms. Fortunately, the ASIF records each firm's main products, which we use both to identify firms operating in the industry and also to further categorize them into their location along the PV supply chain: upstream purification of silicon, midstream production of ingot and wafer and the creation of solar cells, and downstream industry assembly of solar panels. Some firms are vertically integrated and we code these firms separately. To ensure a complete list of firms, we scrutinize each firm's recorded products in each year it appears in the ASIF. There is entry of some firms into the industry from other sectors of the economy. Additionally, we cross-reference our list with the solar company directory provided by ENF Solar, which is considered a comprehensive list of suppliers used by international purchasers of PV products.¹⁹

¹⁹ ENF website: <http://www.enf.cn/>.

3.2 Patent application records and matching

Linking firm data and to patent records is challenging because firm names and locations from the ASIF is recorded in Chinese while international patent information available from DWPI is in English. Consequently, we make use of another dataset named QIN, a Chinese enterprises financial database.²⁰ We use QIN's listing of firms by both their Chinese and English names to obtain English names for those firms we have identified through the ASIF. Through this procedure, we are able to find patent information on about one third of the initial 806 firms.

About two-thirds of the initially identified PV firms are not present in QIN. For these firms, we use the following approaches to get DWPI patents records. First, we use the firms' Chinese names to search patent record in CNKI, which contains patent records in SIPO. Second, the found SIPO patent information (e.g. Publication Number) can be used to trace the same patent record in DWPI, and the latter record typically also contains the firm's English name, from which we can obtain the firm's complete patents records in DWPI. Third, in those few cases where DWPI patent records don't contain the firm's English name, we use company websites to identify English names. Based on the the procedures, we identify almost all Chinese PV firm's patents records in DWPI..

3.3 Firm leaders' international experience record dataset

Obtaining biographical information on each firm's leadership also requires painstaking search procedures. First, we identified each firm's top leaders, including company president, CEO, and ??r important dataset used here is the international experience record for firm leaders. For these executives, we searched for detailed biographies that provided information on their tertiary education and industry experiences. Key sources of information used each company's own official website and public online references to the company and its leaders, such as online newspapers, magazines, and industry publications.²¹ We were able to confirm the biographical information for the

²⁰QIN is a data product of Bureau van Dijk, which provide information on companies around the world. The website is as follows: <https://qin.bvdep.com>.

²¹ To obtain information of the firm's leader (founder or CEO) and the management team (executives other than CEO), we search information from the firms' website and online source. First, we check the firm's official website, where some firms provide official biographies for the leader and management team. Second, if we cannot find the information from the official website, we use internet search engines to find

leaders of 51 firms' president or CEOs as well as 96 firms' other executives were found a record of international education or work experience. 351 firms were found no executives have international background, and the rest 334 firms' information is not available. Here we treat the unavailable information as "no executives have international experience". A similar result comes up when doing the regression if we drop the data with unavailable international experience information.

Using extensive searches of biographical information available from company, industry, and media sources, we obtained information on the leadership of 472 PV firms. Among these, 115 firms have leaders with international experience, accounting for nearly 25% of firms with available information. We found fifty-one firms with a president or CEO who has international experience another ninety-six firms with similarly experienced board members. Among those with international experience, 80% have oversea educational experience and many of them have Ph.D. degrees.

4. Empirical results and discussion

Our data set contains an unbalanced panel of 806 firms over the time period 1998-2008.²² Because the dependent variable is a count of patent applications by firm and year, we use count data panel regression techniques. We present results from both Poisson and Negative Binomial fixed effects regression models (Cameron and Trivedi, 2005; Hilbe, 2011). Below we discuss the advantages and disadvantages of each technique.

We can identify the effects of international experience using both differences between and within firms. In our data, much of the variation in leader's international experience occurs across firms. However, while between-firm variation provides more abundant information on the effects of international leadership, relying on this source of variation alone risks endogeneity bias. A central concern is reverse causation: a firm that has private information about the value of its own R&D may seek out a leader with international experience for reasons unrelated to patenting. If this channel of influence exists, estimation of (1) with a cross-section may lead to the spurious conclusion that

information on the international experience of the firm's leader and management team. Specifically, we use "Google," the largest search engine in the world; and "Baidu," the largest search engine in Chinese.

²² While we have 1746 potential firm/year observations, fixed effect regressions will drop all firms that never patent in any year, as the fixed effect perfectly explains their patenting behavior. This leaves us with 445 unique observations from 106 firms for the fixed effect regressions.

international experience spurs patenting rather than the other way around. Within a short time frame, a firm's R&D productivity is unlikely to change significantly, so a method of reducing the possibility of endogeneity bias is the use of firm fixed effects in our estimation procedure. Another approach is to control for firms' R&D expenditures, although this approach cannot capture the quality of a firm's R&D activities. We use both approaches in our empirics.

The first model we estimate is the negative binomial model, a method often used with overdispersed count data. Our dependent variable, firm-level patent counts, is overdispersed in the sense that the variance in the data is greater than the mean. Our concern about endogeneity leads us to estimate a negative binomial fixed effects (NBFE) regression, which is unusual in that it provides coefficient estimates for time-invariant variables. In our data, only eight of those firms with leaders having international experience undergo a change in this variable (e.g. bringing on a new leader who has international experience). Thus, the NBFE model allows us to better estimate the effect of international experience, as it draws on both within and across firm variation in a fixed effect setting. It also allows us to estimate the effects of time-invariant variable such as firm ownership type. This is possible because the individual fixed effects do not drop out when estimated using conditional maximum likelihood. However, because these fixed effects do not drop out, the NBFE model has the weakness that, unlike most fixed effects models, it does not perfectly control for omitted firm time-invariant characteristics (Allison and Waterman, 2002; Paulo, 2008).

In contrast, a Poisson fixed effects (PFE) model allows us to better control for any unobserved time-invariant firm characteristics that may affect firm-level innovation. While the Poisson model assumes that the mean and variance of the data are the same, it provides consistent estimates even if the data are overdispersed. Robust standard errors can then be used to adjust for overdispersion (Cameron and Trivedi 2005). Thus, the PFE model provides consistent results even if there are unobserved firm characteristics that bias the NBFE results, making it better suited for a causal argument. However, this model enables us to identify the effects of international experience only by the outcomes for those few firms switching status. Given these tradeoffs, we present both the NBFE and PFE results.

4.1 Intellectual returnees and technology innovation

Our results suggest that intellectual returnees both improve a firm's technology innovation capacity and provide spillover effects to neighboring firms. These results suggest that returning intellectuals are an important source of technology transfer. Looking first at Table 2, we see that firms whose leader has international experience have between 138% (NBFEE – column 1) and 379% (PFE – column 2) more patents than other firms. Similarly, having an executive board member with international experience increases patenting by 89% (NBFEE) to 165% (PFE).

Recall that the NBFEE estimation does not condition on unobserved fixed effects, so it identifies the effect of experience from both differences between and within firms. However, the results may be biased if, for example, a firm that has private information about the value of its own R&D seeks out a leader with international experience. In this case, we would expect any such bias to be positive – e.g. more innovative firms, who are likely to patent more frequently anyway, will be more likely to seek out those with international experience. In contrast, the PFE controls for such unobserved firm characteristics. Nonetheless, the PFE effect of leadership is higher than that estimated using the NBFEE model, suggesting that this sort of bias may not be a concern. We emphasize, however, that since our sample only allows us to identify the leadership effect by changes at a few firms, future research should attempt to replicate our results in a broader sample. However, given the consistency across the two methods, we believe that the results provide strong evidence that returnees play an important role in innovation.

Clustering of PV firms is common and interactions among PV firms have been identified as a notable channel for technology transfer (de la Tour, et al, 2011). Examples of these interactions include input-output linkages, technology cooperation, labor market sharing, and personal communication between firm leaders. Our fixed effects results provide evidence that these clusters are not only important, but that they are an important channel of spillover benefits from international experience. As shown in column 2 of Table 2, index of international experience spillover is 0.876, suggesting that the benefits of returnees' international experience are shared among neighboring firms.

The significant effect of international experience remains robust when separating the

results by patent type in Table 3. Table 3 presents separate results for invention patents, utility and design patents, and process patents. Process patents are a subset of both invention and design patents that protect innovations designed to improve the production process, rather than advancements in the solar cells themselves. The international experience of a firm's leader remains large and significant across all three patent types and across both the NBFEE and PFE models. Interestingly, the international experience of executive board members is important for utility and design patents and process patents, but not for the more significant invention patents. These more minor innovations typically represent adaptive innovation based on current technology and are easier to achieve while still improving product quality or reducing cost. In contrast, firms whose leaders have international experience are also more likely to do major innovations, as shown by their increased likelihood of receiving invention patents.

4.2 R&D and patenting activity

Table 4 provides descriptive statistics on the level of R&D spending by firms with and without international experience. These data are only available for three years in our sample: 2005-2007. However, they provide some evidence that firms with internationally experienced leaders are more active researchers. Such firms do more total R&D and spend more on R&D per worker than do other firms.

Table 5 considers whether international returnees place more value on patent protection than other firm leaders. We address this by including firm R&D spending as an explanatory variable. These results depend on a smaller sample, given the limited availability of the firm-level R&D data.

Column (1) of Table 5 presents results from a Poisson fixed effects regression. The interpretation of the regression including R&D is different from those previously shown. When R&D is included, the regression estimates a patent production function – that is, how additional research inputs translate into research outputs. Thus, the large positive coefficients in column (1) do not tell us that firms with international experience are more innovative. Rather, they tell us that, conditional on levels of R&D spending (e.g. research inputs), firms with international experience obtain more patents. These returnees in general are more familiar with technology frontiers, and they may as well be

more aware of the importance of intellectual rights protection given by patenting.

One troubling aspect of the results in column (1) is the insignificant coefficient on R&D. This result is inconsistent with other recent studies examining R&D and patenting in China, such as Eberhardt et al. (2012) and Hu and Jefferson (2009). A complication is that the fixed effects model can only be estimated on firms that patent at least once during the 2005-07 sample period, resulting in just 155 observations. Column (2) addresses this by using a random effects model. This expands the sample size to 705, but has the drawback that the estimates are not consistent if the unobserved individual random effects are correlated with the explanatory variables. This could be the case, for instance, if more innovative firms attract leaders with international experience. Nonetheless, given small sample size issues that arise when working with Chinese data, it is not uncommon to include random effects results when estimating patent production functions (see, for example, Eberhardt et al. 2011, Hu and Jefferson 2009, and Huang and Wu 2012).

The random effect results allow us to verify the importance of R&D, but coefficients on leader experience should be interpreted with caution, given potential unobserved effects that could determine both international experience and patenting. Column (2) shows that, as expected, firms doing more R&D are more likely to patent, with an elasticity of 0.057. Finally, to ascertain the role of the changing sample size, column (3) reruns the random effects regression on just those 155 observations including firms that patent at least once from 2005-07. Once again the effect of R&D is insignificant and nearly 0. Thus, the significant coefficient found in column (2) comes not from differences between the random effects and fixed effects model, but because of differences between those firms that do or do not patent. However, the coefficients on international experience are lower in both random effects models than in the fixed effects model, suggesting that unobserved characteristics of firms are important, verifying the importance of using fixed effects to estimate the effects of international experience on patenting.

4.3 Other determinants of firm innovation

As noted in section 5.1, industry agglomeration provides an important channel for

spillover benefits from international experience. Therefore, we also include a direct measure of industry clusters to see if other agglomeration benefits, such as input-output linkage, labor market sharing and knowledge spillover, enhance technology innovation. The evidence for these benefits is limited; the coefficient is only significant in the PFE model and only at the ten percent level. In Table 3, we see that, even at the 10 percent level, industry agglomeration is only important for utility & design and process patents. Thus, general agglomeration effects appear unimportant for more significant innovations. Similarly, our NBFEE models include controls for geographic proximity to a top university. This location characteristic also has no additional impact on patent levels.

International trade is usually regarded as an important channel of international technology transfer, both through the importation of advanced capital equipment and through learning by exporting. To investigate the learning by exporting channel, the regressions in both Tables 2 and 3 include controls for firm export intensity. Domestic firms may gain access to foreign technology through exporting, or may be pressured by competition to improve products for export markets. While both can help raise innovation performance (Clerides and Saul et al., 1998; Bernard and Jensen, 1999), we find no evidence of a link between patenting and export intensity for Chinese PV firms.

Table 2: Negative Binomial & Poisson Fixed-Effect Estimation, Total Patents Count

| Dependent Variables | Total Patent Count | |
|--|--------------------------|----------------|
| | [1]-Negative Binomial FE | [2]-Poisson FE |
| InternationalExperience _i – leader | 1.384*** | 3.792*** |
| | 0.436 | 0.374 |
| InternationalExperience _i – executive | 0.894** | 1.649*** |
| | 0.407 | 0.402 |
| log(InternationalExperienceSpillover _{it}) | 0.198 | 0.876** |
| | 0.236 | 0.375 |
| log(IndustryCluster _{it}) | -0.0444 | 0.289* |
| | 0.11 | 0.164 |
| log(IndustryUniversity _i) | -0.016 | - |
| | 0.166 | - |
| log(MarketPower _{it}) | 0.426*** | -0.357** |
| | 0.157 | 0.166 |
| log(Export _{it}) | -0.162** | 0.0794 |
| | 0.0635 | 0.0868 |
| log(Age _{it}) | 0.049 | 0.0557 |
| | 0.131 | 0.239 |
| log(Size _{it}) | 0.058 | 0.382 |
| | 0.153 | 0.246 |
| Log-Likelihood | -337.48 | -503.61 |
| Number of Observations | 445 | 445 |

Notes: Estimation also includes year effect, firm ownership type and category dummies. Firm ownership types are state, foreign, Hong Kong, Taiwan and Macau, collective, and private owned. Firm categories are purification, process, panel, comprehensive and other solar firms. * p<0.10, ** p<0.05, *** p<0.01

Table 3: Negative Binomial & Poisson Fixed-Effect Estimation, Patents Count by Type

| Dependent Variables | Invention Patent | | Utility & Design Patent | | Process Patent | |
|--|-------------------|-------------------|-------------------------|-------------------|--------------------|-------------------|
| | [1]-NBFE | [2]-Poisson FE | [3]-NBFE | [4]-Poisson FE | [5]-NBFE | [6]-Poisson FE |
| InternationalExperience _i – leader | 2.162*** 0.662 | 3.232*** 1.072 | 1.179* 0.667 | 14.00*** 0.983 | 1.446*** 0.479 | 3.375*** 0.378 |
| InternationalExperience _i – executive | 0.141 0.788 | 14.09 671.2 | 1.054** 0.498 | 1.523*** 0.425 | 0.986** 0.42 | 1.640*** 0.394 |
| log(InternationalExperienceSpillover _{it}) | 0.405 0.434 | 1.279*** 0.403 | -0.133 0.285 | 0.678 0.477 | 0.156 0.241 | 0.748** 0.369 |
| log(IndustryCluster _{it}) | 0.0625 0.142 | 0.00745 0.106 | 0.0396 0.13 | 0.414* 0.218 | -0.00104 0.11 | 0.331* 0.173 |
| log(IndustryUniversity _i) | -0.269 0.295 | - - | -0.0936 0.22 | - - | 0.0043 0.171 | - - |
| log(MarketPower _{it}) | 0.258 0.209 | -0.0829 0.15 | 0.320* 0.19 | -0.445* 0.233 | 0.383** 0.156 | -0.383** 0.177 |
| log(Export _{it}) | -0.0342 0.0867 | 0.0922 0.0564 | -0.0535 0.0845 | 0.0921 0.11 | -0.142** 0.0668 | 0.0746 0.0929 |
| log(Age _{it}) | -0.213 0.198 | -0.238 0.181 | 0.0709 0.146 | 0.138 0.23 | 0.0871 0.135 | 0.102 0.214 |
| log(Size _{it}) | 0.0534 0.208 | 0.328* 0.176 | -0.204 0.205 | 0.296 0.282 | 0.00723 0.156 | 0.346 0.248 |
| Log-Likelihood | -187.94 | -224.54 | -232.72 | -336.69 | -316.73 | -445.37 |
| Number of observations | 326 | 326 | 370 | 370 | 445 | 445 |

Notes: Estimation also includes year effect, firm ownership type and category dummies. Firm ownership types are state, foreign, Hong Kong, Taiwan and Macau, collective, and private owned. Firm categories are purification, process, panel, comprehensive and other solar firms. * p<0.10, ** p<0.05, *** p<0.01

Table 4: R&D expenditures by Chinese PV firms (in thousand RMB)

| | | R&D per firm | R&D per worker |
|--|--|--------------|----------------|
| Among firms in PV industry | | 1001.522 | 4.211786 |
| Annual Trends for all firms | 2005 | 546.943 | 2.635852 |
| | 2006 | 937.1053 | 4.501227 |
| | 2007 | 1264.471 | 4.768032 |
| Firms with or without international experience | Leader has international experience | 1385.154 | 8.168658 |
| | Executives have international experience | 2070.018 | 6.144731 |
| | No international experience | 785.8827 | 3.74955 |

Table 5 Poisson Estimation: R&D as Control Variable (Total Patents Count, 2005-2007)

| Dependent Variables | Total Patents Count | | |
|--|---------------------|------------------------------|------------------------------|
| | [1]-Poisson FE | [2]-Poisson RE | [3]-Poisson RE |
| Estimator | | | |
| Samples | - | Using full sample(2005-2007) | Using the same sample as [1] |
| InternationalExperience _i – leader | 14.92*** 1.32 | 0.528 0.656 | -0.356 0.415 |
| InternationalExperience _i – executive | 16.46*** 1.746 | 2.239*** 0.501 | 1.374*** 0.375 |
| log(InternationalExperienceSpillover _{it}) | -0.72 0.916 | 0.00512 0.209 | -0.0304 0.188 |
| log(IndustryCluster _{it}) | 0.473** 0.191 | 0.380*** 0.0897 | 0.397*** 0.0841 |
| log(IndustryUniversity _i) | - - | -0.151 0.14 | -0.0871 0.116 |
| log(MarketPower _{it}) | -0.902*** 0.276 | -0.772*** 0.125 | -0.630*** 0.123 |
| log(Export _{it}) | -0.0579 0.147 | -0.00768 0.0578 | -0.0821 0.0556 |
| log(Age _{it}) | 0.397* 0.222 | 0.119 0.112 | 0.0822 0.125 |
| log(Size _{it}) | 0.385 0.319 | 0.444*** 0.149 | 0.295** 0.135 |
| log(RD _{it}) | 0.0121 0.0701 | 0.0573*** 0.022 | 0.0112 0.0202 |
| Log-Likelihood | -155.20 | -468.33 | -326.05 |
| Number of observations | 155 | 705 | 155 |

Notes: Estimation also includes year effects and firm ownership type. Firm ownership types are state, foreign, Hong Kong, Taiwan and Macau, collective, and private owned. * p<0.10, ** p<0.05, *** p<0.01

5. Concluding remarks

According to prior empirical research on Chinese PV firms, international technology transfer is significant to China's industry development and technology innovation; however, the role of different channels varies much. Intellectual returnees, as the special channel of international technology transfer, are playing a crucial role in China's technology innovation capacity improvement.

This study firstly analyzes the role of China's intellectual returnees from firms' perspectives, which is based on the 806 Chinese solar photovoltaic firms' statistics and patents record during 1998-2008. Under the control of other variables and employing a

comprehensive model as well as firm fixed effect, the study focus on the role of intellectual returnees. International experience are found significant to firms' technology innovation, and has significant spillover effects as well as make firms tend to do more patenting. Moreover, the role of exporting is found insignificant here. These findings can provide some policy implications.

Attracting intellectual returnees is more effective than foreign capital to a certain extent, especially in the newly emerging industry. Comparing to the potential crowding out effect of FDI, intellectual returnees has spillover effect instead. In the context of China, industry upgrading and economic structure transforming is strongly required to achieve a sustainable development. The intellectual returnees can greatly contribute to the development of newly emerging industry and indigenous technology innovation capacity. China's policy makers, as well, have incrementally notice the importance of leading talents. There are now many central program or local policy focusing on attracting intellectual returnees. As more and more oversea talents go to China and start up, their roles will become much greater day by day.

As awareness of the role of returnees in indigenous innovation grows, immigration and overseas training policies are evolving in sending countries. China's "going out" policies continue to develop and now include not only incentives for the return of émigrés, but also imperatives in some sectors for overseas experiences. These policies are supported by the success of new high-tech firms, including the 2000 firms set up by returnees in China's Zhongguancun Science Park, Beijing's Silicon Valley (Filatotchev et al., 2011). According to China's official statistics, more than 500 thousand Chinese students returned after training abroad during 1978-2009. In the next five years, an estimated 500,000 Chinese students will be educated abroad and an estimated 300,000 will return to China (Wang and Lai et al., 2010; Li and Xu, 2011). The resulting "brain circulation" is sure to influence China's ability to compete in production of high-tech and newly emerging sectors and influence trade patterns for years to come.

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