

Innovation in China: The Rise of Chinese Inventors in the Production of Knowledge

IFS Working Paper W11/15

Rachel Griffith
Helen Miller

Innovation in China: the rise of Chinese inventors in the production of knowledge

Rachel Griffith

Institute for Fiscal Studies and University of Manchester

and

Helen Miller*

Institute for Fiscal Studies

June 2011

Abstract:

In 2010 China was the world's fourth largest filer of patent applications. This followed a decade of unprecedented increases in investment in skills and Research and Development. If current trends continue China could rank first in the very near future. We provide evidence that the growth in Chinese patenting activity has been accompanied by a growth in Chinese inventors creating technologies that are near to the science base.

Part of the success of China has been to attract the investment of foreign multinationals. This is also true for a number of other Emerging Economies. Europe's largest multinational firms increasingly file patent applications that are based on inventor activities located in emerging economies, often working alongside inventors from the firm's home country.

JEL: F21; F23; O3

Keywords: China; innovation; offshoring; patents.

Acknowledgement: We would like to thank Laura Abramovsky and Jonathan Cribb for working with us on an earlier version of this paper. We acknowledge financial support from the Economic and Social Research Council through the Centre for the Microeconomic Analysis of Public Policy (CPP) at the IFS, through the Advanced Institute for Management Research (AIM) and through the grant RES-180-25-0003.

* Corresponding author. Institute for Fiscal Studies, 7 Ridgmount Street, London, WC1E7AE, UK. E-mail address: helen_m@ifs.org.uk (H. Miller). Telephone: +44 207 291 4800; Fax: +44 207 323 4780.

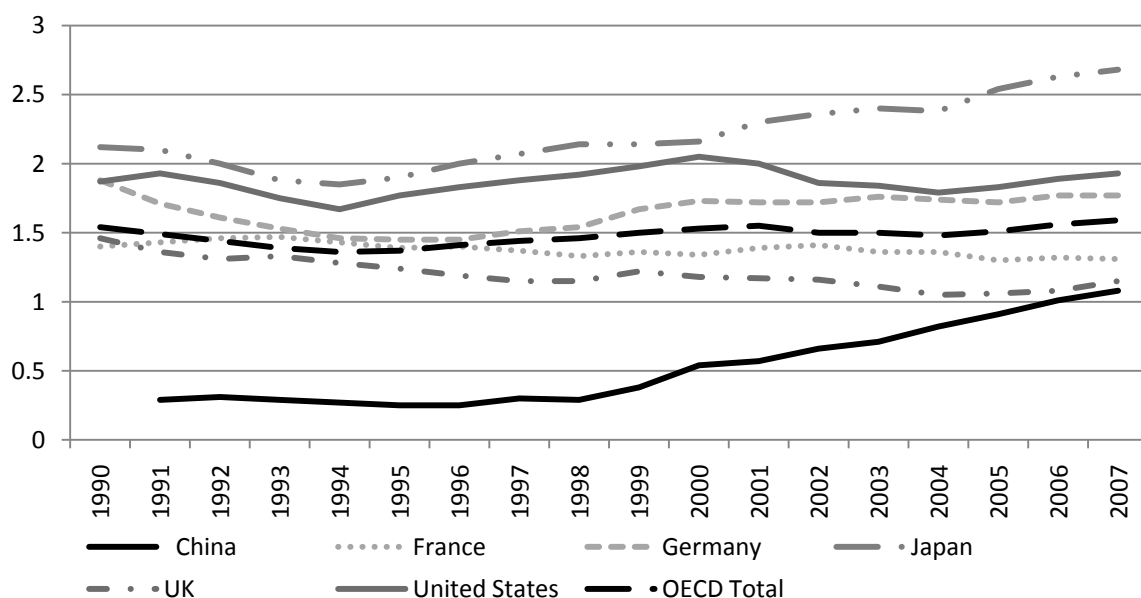
1 Introduction

Over the last decade emerging economies have seen impressive growth in innovative activities. None has been more impressive than China.

China's economic growth – which led it to overtake Japan in 2010 to become the world's second largest economy – and rapidly expanding role in world production has commanded widespread attention.¹ More recently, the focus has shifted to China's technological performance, with a range of statistics showing that innovative activities in China are growing at an astounding rate.

There have been large increases in the number of Research and Development (R&D) centres in China (UNCTAD (2005)) and business expenditure on Research and Development (R&D) as a proportion of GDP has increased at an annual rate of almost 19% since 1995, see Figure 1, leading China to become the sixth largest in terms of worldwide R&D (OECD (2008b)). This increase has been partly driven by Western multinationals, which account for around 25-30% of private R&D expenditure in China, (OECD (2008b, p58)).

Figure 1: Business expenditure on R&D as a percentage of GDP



Source: MST Indicators, OECD 2009.

At the same time there has been a rapid increase in educational attainment (Li, Fraumeni, Liu and Wang (2009)). In particular, there has been a proliferation of Chinese graduates (Freeman, (2009), many of whom study subjects relevant for high tech research: in 2007

¹ For an overview of China's growth see Feenstra, R. and S. Wei (2009) and chapter 9, OECD (2008a).

China topped the OECD ranking of the proportion of degrees which are in science and engineering (47%) (OECD (2010)). The investment in research and skills has been translated into equally impressive growth in innovative outputs. For example, in 2010 China was the fourth largest filer of patent applications to the World Intellectual Property Organization (WIPO (2010)) and under a naive (linear) projection of current trends could be the world's largest by 2015.

That China is now a significant presence in creating innovation is relatively uncontroversial. However, whether China is operating at, or even moving towards, the technological frontier is widely disputed. A large part of the academic literature has argued that investment and trade patterns show that China still lags behind the West in terms of technological sophistication, and that technology expenditure in China is still predominantly focused on the lower technology end of research and development (R&D).² In contrast, anecdotal evidence suggests that China is increasingly operating at the technological frontier and has been successful in attracting the cutting-edge research of foreign firms.³ Public perception in the West largely supports this view of China. For example, a recent survey in *Newsweek* showed that only 41% of Americans believed that the US is staying ahead of China in terms of innovation.⁴ The type of activity that is being conducted is important. Emerging economies are keen to reap the rewards of introducing new products and processes and making scientific advances. At the same time, it is exactly this type of activity in which the West has (and wants to maintain) a comparative advantage.

In this paper we use detailed data on patent applications – important outputs from innovation – to consider the innovative activities taking place in China. We are not the first to use patents data for this purpose (see, for example, Belderbos (2006) and Puga and Trefler (2009)). We make two contributions. Firstly, we present new evidence on how technologically advanced Chinese activity is; we use data on patent citations to the scientific literature to measure activities which are 'near science'.⁵ This is distinct from the academic literature to date which has used information on the technological sophistication of China's

² See Branstetter and Foley (2007), OECD (2008b), Puga and Trefler (2010), Thursby and Thursby (2006) and von Zedtwitz and Gassmann (2002), the conclusions of which are discussed in section 3.

³ Examples abound of companies establishing facilities in China to perform cutting-edge research (see *Economist* (2010)). For example, in 2007 GlaxoSmithKline opened a R&D centre in Shanghai, stating that the centre would contribute to the firm's global discovery activities.

⁴ See the *Newsweek*-Intel Global innovation survey (<http://www.newsweek.com/id/222979>); an online survey of 4,800 adults in the US, China, Germany, and UK regarding views relating to innovation.

⁵ For a general discussion of the use of patent citations see Jaffe and Trajtenberg (2002).

export pattern (Rodrik (2006), Schott (2008) and Wang and Wei (2008)), or on the composition of Foreign Direct Investment (Branstetter and Foley (2007)). Contrary to previous findings we show that Chinese innovation is at least as technologically advanced as that in the West. Secondly, we show an increase in Western European multinationals creating new knowledge using inventors located in emerging economies, especially China.

Like China, other emerging economies have made significant investments in R&D and skills and seen increases in innovative outputs (OECDa).⁶ Emerging countries have been successful in creating an attractive environment for investment by foreign firms. A 2010 survey of business leaders reported that China, Eastern Europe and India are perceived to be the most attractive regions for FDI over the next three years. At the same time “Western Europe’s appeal as the most attractive destination for FDI collapsed from 68% of votes in 2006 to 38% in 2010” (Ernst & Young (2010)). *The World in 2025* highlights that Asia, in particular China and India, is set to become the main destination for the location of business R&D by 2025 (European Commission (2009)).

The most recent data shows that Western multinationals are increasingly locating innovative activities in emerging economies (UNCTAD (2005)). OECD (2009) discusses the importance of multinational firms as drivers of global R&D and knowledge transfer, noting large increases in the share of global multinational R&D expenditure undertaken by foreign affiliates in developing countries (from 0.8% in 1996 to 6.2% in 2002) and concluding that, while developing economies still have a way to go to catch up with the West’s knowledge base, “it is the outward flows of FDI by the multinational firms from developed economies which will facilitate, encourage, and enable this process” (OECD (2008a, p96)).

We show that, while the amount of innovative activity conducted by Western firms in emerging economies is still relatively small, it has increased dramatically, driven by a handful of large multinational firms. While knowledge is created in emerging economies, the resulting intellectual property is predominately held in Western firms’ home countries. This is consistent with firms applying the knowledge created by inventors in emerging economies in technology destined for the European markets, and with firms keeping intellectual property at home to overcome weak property rights regimes in emerging

⁶ For information on investment and increased innovation in Eastern Europe see Carstensen and Toubal (2004), Marin (2006) and Economist Intelligence Unit (2008), appendix 1; in relation to India see Shukla (2005).

economies. In addition, Chinese inventors often work alongside inventors from the firm's home country in creating patentable technologies. This is likely to aid the flow of knowledge across different parts of the firm. We find no evidence to that Chinese inventors are more likely to be working in teams when creating near science innovations than other innovations.

The growth in innovation in emerging economies (both by domestic firms and Western multinationals) has led to concerns in the West that China's progress may lead it to rival the West's positions as technological leaders, and potentially result in a loss of high skilled jobs. The European policy debate had focus heavily on the relatively low proportion of GDP that is invested in R&D. The latest figures (2007) show that business expenditure on R&D in the EU-15 amounts to 1.2% of GDP compared with 1.9% in the US and 1.1% in China.⁷ There has been a particular concern in the UK, where levels of business R&D intensity are low (1.15% in 2007) and have been declining. The Lisbon target to substantially increase R&D spending by 2010 will be missed by a large margin (see van Pottelsberghe (2008)). Concerns also stem from the much more rapid increase in investment by firms in emerging economies, and the surveyed opinion that Europe is becoming an increasingly less desirable location for R&D. (Ernst & Young (2010))

These concerns are not completely unfounded. Soete (2009), in work prepared for the European Commission, concluded that if the recent trends in R&D continue then "in 2025, the United States and Europe will have lost their scientific and technological supremacy for the benefit of Asia". Freeman (2006, 2009) outlines the potential for shifts in the global job market for science and engineering workers towards China to erode US dominance by diminishing the current comparative advantage in high tech production. Articulating many of the concerns in the West, he says that the increase in highly skilled graduates in China "threatens to undo the 'North-South' pattern of trade in which advanced countries dominate high tech while developing countries specialize in less skilled manufacturing".⁸

⁷ Source: MST Indicators (2009); Business Expenditure on R&D (BERD) as a proportion of GDP.

⁸ Li, Whalley, Zhang and Zhao (2008) and Freeman (1995) also discuss the global implications of the increase in skills in China. There is also literature on the impact of low wage competition in production on the West, which finds mixed results. For example, Liu, and Trefler (2008) consider the impact of outsourcing to China on the U.S. labour market, finding only very small effects. Bloom, Draca and Van Reenen (2008) present evidence that Chinese import competition has reduced employment growth in European countries but has led to an increase in firms adopting information technology. Bernard, Jensen and Schott (2006) consider the impact of US manufacturing industries' exposure to low-wage country imports and find a negative association with plant survival and growth.

Such concerns have been reported widely in the media⁹ and have permeated the policy debate. For example, the introduction to Obama's American Recovery and Reinvestment Act, which saw massive increases in spending on science in the US, states, *"We'll provide new technology and new training for teachers so that students in Chicago and Boston can compete with kids in Beijing for the high-tech, high-wage jobs of the future,"*¹⁰

However, innovation is not a zero-sum game; the success of emerging economies need not be at the expense of the West. Indeed, as we return to discuss in the conclusions, there are many channels through which the West can benefit from technological advances in emerging economies. The key is for knowledge economies to continue to invest in skills and science such that they are in a position both to compete for and to engage collaboratively in tomorrow's breakthroughs.

The paper is structured as follows. Section 2 documents the rise of Chinese patenting activity using the most recent statistics available. Section 3 uses data on patent applications filed to the European Patent Office (EPO) to provide new evidence on how close the knowledge created in China is to the science base. Section 4 considers the activities of Western European multinationals using inventors in emerging economies to create patentable technologies. A final section concludes.

2 Patenting in China

The most recent data show that in 2010 China ranked fourth in the world in terms of the number of Patent Cooperation Treaty (PCT) applications filed,¹¹ behind only the US, Japan, and Germany, see Figure 1. China's current standing represents rapid growth over the last decade. In 2000, Chinese applications filed 2,503 PCT patent applications (1.8% of the total) and ranked 10th. By 2010 this number had reached 12,293 (7.5% of the total). Between 2009 and 2010 there was a 55% growth in the number of PCT applications filed by Chinese applicants – a stark contrast to the fall in applications filed by applicants in the US and many Western European countries.

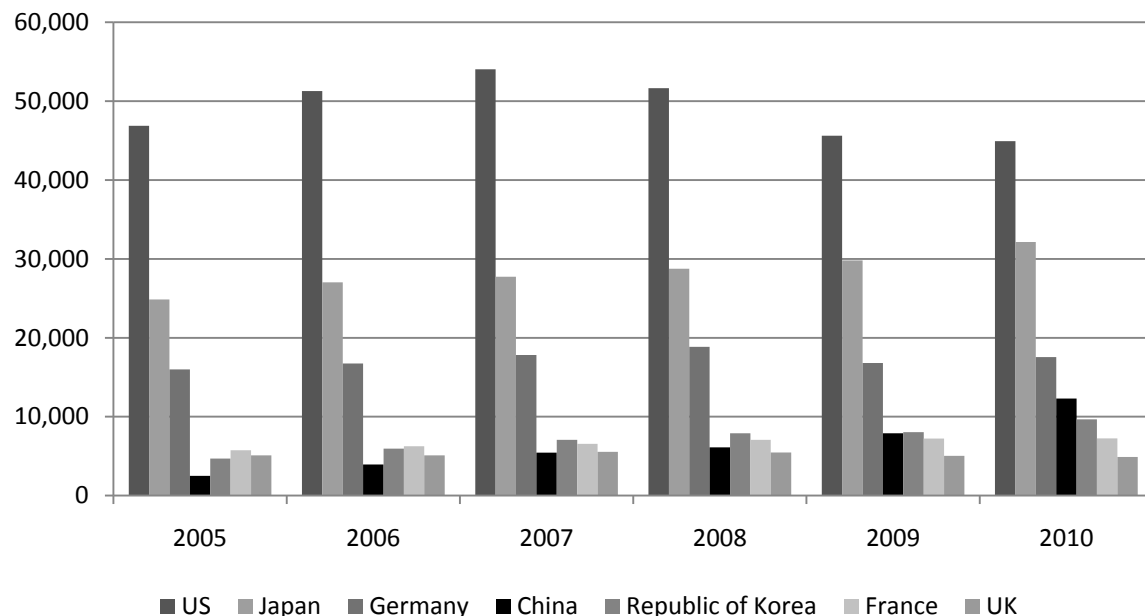
⁹ For examples of media coverage see, "Nightmare Scenarios", The Economist, 5 October 2006 or "How to Keep Your Job Onshore" at Business Week, 20 August 2007.

¹⁰ See page 2 of the President's Message in the 2009 Budget (fiscal year 2010); available here: <http://www.gpoaccess.gov/usbudget/fy10/pdf/budget/message.pdf>

¹¹ The Patent Cooperation Treaty (PCT) is administered by the WIPO and allows applicants to obtain patent protection in any or all of the national and regional offices covered by the PCT. For further discussion and statistics see WIPO (2009) and WIPO (2010).

Individual Chinese firms have also become more prominent in the world rankings. In 2010 ZTE Corporation was the second largest filer of PCT patent applications and Huawei Technologies the fourth largest (having been the largest in 2008 and second largest in 2009).¹²

Figure 1: Number of PCT patent applications, by country of patent applicant



Notes: The height of each bar shows the number of patent applications filed under the Patent Cooperation Treaty. Country refers to the country of the first named applicant. Years refer to the international filing date. Source: WIPO Statistics Database, June 2011, <http://www.wipo.int/ipstats/en/statistics/pct/>.

The growth in the number of patent applications filed by Chinese applicants is noteworthy, but the absolute number is still significantly smaller than the equivalent for the US: in 2010 US applicants filed 44,925 PCT patent applications, more than 3 times as many as Chinese applicants. The relative levels of patenting activity have been used to assuage concerns of China's rise (see, for example, Branstetter and Foley (2007)). However, if the recent trends in patenting continue, how long would it take before the number of patent applications filed by Chinese applicants was equally to the number filed by US applicants? We can't know how patenting will evolve in the two countries in the coming years. Nonetheless it is interesting to consider how long it would take China to 'catch up' under different scenarios.

In the 5 years to 2010, the number of PCT patent applications filed by a Chinese applicant grew at an average rate of over 35% per year. The same figure for those with a US applicant

¹² See WIPO Statistics Database, January 2011.

was negative. If the number of PCT applications filed by US applicants remained at its 2010 level while the number associated with Chinese applicants grew at a rate of 35%, there would be as many PCT patent applications filed by Chinese applicants as by US applicants by around 2015. If instead we assume US growth of 2.5% and Chinese growth of 10% (a lower rate than it had in any of the last 5 years), China would match the US before 2030.

The rapid increase in Chinese applicants' patent applications is not an artefact of considering PCT applications. We, and others, find similarly large growth in the applications filed to the EPO (Belderbos (2006)), the US Patent and Trademarks Office (USPTO) (Puga and Trefler (2009)) and the Chinese State Intellectual Property Office (Frietsch and Wang (2007)). It has, however, been well documented that part of the increase in patenting at the SIPO has been driven by government policies that provide large fiscal incentives to file applications (for example, high patenting firms may see corporation tax sharply reduced or be more likely to be awarded contracts) and by firms linking employees' bonus payments to applications.¹³

These trends obviously do not take account of any of the many reasons why growth in patent applications may not continue linearly. For example, China may not have the skilled labour force, or other infrastructure, required to sustain such a level of growth. In addition, recent research has highlighted the increasing costs associated with creating innovations (see Jones (2009)), with potential implications for the number of patentable ideas. On the other hand, the large investment in R&D and skills show little sign of slowing and can be expected to feed through into patentable technologies.

3 Moving towards the technology frontier?

The Chinese government has increased incentives for innovation.¹⁴ In 2006, China's President, Hu Jintao, launched a plan to make China an innovation-oriented economy and leading science and technology power, proclaiming that "by the end of 2020... China will

¹³ The financial incentives to file patent applications are discussed in "Patents, yes; ideas, maybe. Chinese firms are filing lots of patents. How many represent good ideas?", *The Economist*, Oct 14th 2010.

¹⁴ For a discussion of Chinese policy measures see section 2.8 and chapter 11 of OECD (2008b).

achieve more science and technological breakthroughs of great world influence, qualifying it to join the ranks of the world's most innovative countries".¹⁵

There is disagreement over the type of activities that are being conducted in China and, specifically, whether Chinese inventors are engaged in leading-edge science, rather than just incremental and imitational research. In contrast to the public perception, the majority of the academic literature to date has argued that China lags behind the West in technological sophistication. Puga and Trefler (2010) show the growing importance of Chinese innovation, but emphasise that it is largely incremental in nature. An OECD report concludes that, while China is a major science and technology player in terms of inputs to innovation, the R&D activity conducted is "more "D" than "R"", OECD (2008b, p49). Branstetter and Foley (2007) analyse a range of data sources and conclude that China is *"far from becoming a technological superpower"*. The literature also provides evidence that, while Western multinationals now locate more activity in China, it is not of a technologically advanced nature. von Zedtwitz and Gassmann (2002) provide survey evidence that the 'research' part of multinational firms' R&D is still being conducted in developed countries rather than China. Thursby and Thursby (2006) survey 250 R&D managers and conclude that firms keep research on new technologies in developed countries, and that the activities in emerging countries are largely not new to science or to the firms that carry them out. In contrast, there is some recent literature which proposes that multinational's Chinese R&D facilities may have moved up the value chain over time (Chen 2007; Medcof 2007), and that firms are increasingly locating higher-tech activities there (Schwaag Serger 2007; Sun et al. 2006). In support of this, Zhou and Leydesdorff (2006) show that citations to papers written by Chinese authors, which are taken to signal quality, have increased dramatically in recent years.

The evidence presented above suggests that China is set to rival the US in terms of the number of patent applications. But are Chinese inventors involved in leading edge science – are they moving towards the technology frontier?

To consider the sophistication of patented technologies we use information on the citations to prior art, as listed on European Patent Office (EPO) patent applications. Patent

¹⁵ The Chinese government's 2006 'Medium- and Long-term National Strategic Plan for Science and Technology Development' included a range of targets (including to increase R&D intensity to 2.5% by 2020) and policy measures. See Box 2.3, OECD (2010). See Wilsdon and Keeley, (2007) for quote (from a speech given 9 Jan 2006).

applications are legal documents, and it is required to list citations to prior art, which includes previous patents and the scientific literature. These are often added by patent examiners.¹⁶ We consider those patent applications that cite a paper in the scientific literature to represent ideas that are closer to the science base (from now on, *near science*) than patents that cite only other patents.¹⁷ Near science patent applications represent more fundamental research and scientific discovery of products or processes that are new to the market.¹⁸ We consider those patent applications which are created using Chinese inventors – the location of inventors captures where innovative activity is taking place (regardless of whether the resulting intellectual property is owned by a Chinese or foreign firm).

There are many more near science patent applications that list US inventors than there are that list Chinese inventors. In 2005 there were 15,377 near science EPO patent applications, of which 2,936 listed a US inventor (19%) and 450 listed a Chinese inventor (3%). The small percentage of Chinese inventors on near science patent applications could be interpreted as suggestive that China is not rivalling the US at the technology frontier. However, this statistic lacks context. The trends set out above suggest that, even though there are currently fewer Chinese than US patent applications, the rapid growth indicates they are likely to converge soon. We alternatively consider all Chinese patenting activity, and consider the type of activity that Chinese inventors are involved in, i.e. we consider the proportion of activity which is near science.

Overall, the share of EPO patent applications that are near science, shown by the solid line in Figure 2, has declined steadily from 35% in 1995 to 12% in 2005. This is consistent with other evidence showing that much of the growth in EPO patent applications over the past two decades has been due to low quality patents (see, for example, Eaton, Kortum and Lerner (2004), Guellec and van Pottelsberghe (2007) and Jones (2009)).¹⁹

¹⁶ For discussion of the use of patent citations in economics see Griliches (1990) and Jaffe and Trajtenberg (2002).

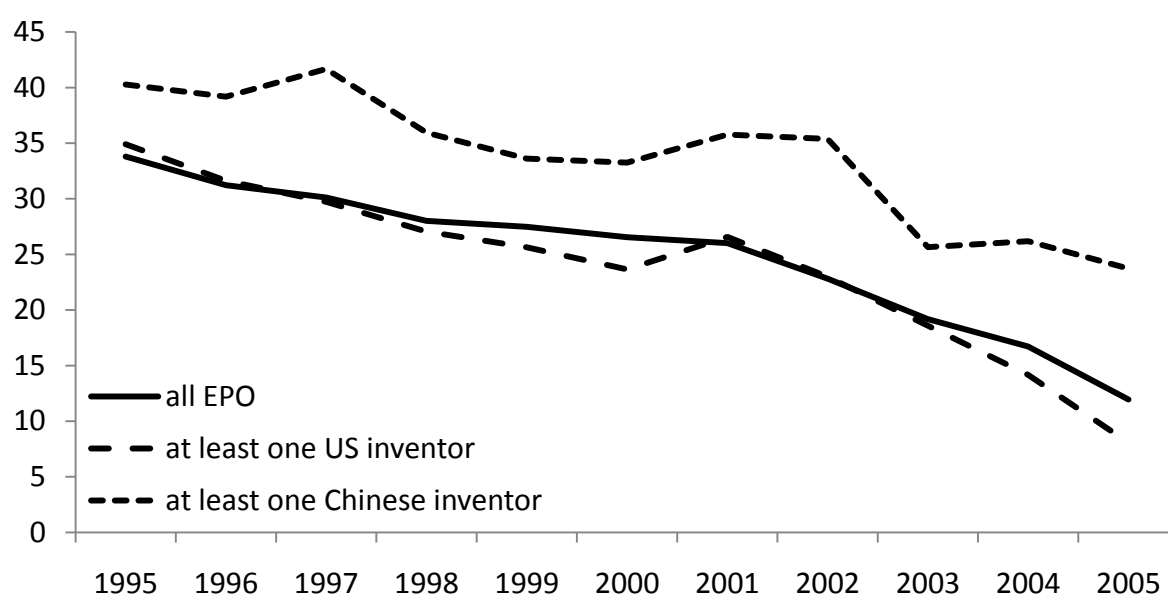
¹⁷ For two examples of patent applications that cite the scientific literature see application numbers EP06020518, which cites a graduate school master thesis – and EP06114355, which cites several academic journal articles. The full patent applications can be seen at <https://data.epo.org/publication-server/?lg=en>.

¹⁸ Griffith and Macartney (2010) provide evidence that a measure of near science based on citations to scientific literature captures new products well (for example, the measure is correlated with employment adjustment and sales volatility at the firm level, indicating that these patents represent radically new products or processes), and that industries expected to require highly scientific innovations have the highest proportion of near science patents.

¹⁹ Jaffe and Lerner (2004) show a similar shift towards low quality patent applications at the USPTO. Stevnsborg and van Pottelsberghe (2007) consider possible firm strategies behind these trends, including firms splitting patent applications into several smaller subsequent patents.

The proportion of patent applications listing at least one US inventor that are near science, shown by the long-dashed line in Figure 2, indicates a similar decline to all EPO applications. In contrast, the proportion of patent applications with at least one Chinese inventor that are near science, shown by the short-dashed line, is both higher and has declined less rapidly.²⁰ Indeed, while there has been a sharp decline in the absolute number of near science patent applications made to the EPO overall (from around 30,000 in 2000 to 15,000 in 2005), there has been an increase in the number with Chinese inventors (from fewer than 150 in 2000 to 450 in 2005) .

Figure 2: Proportion of EPO patent applications that are near science



Notes: The data include all EPO patent applications. Years refer to the application priority year of the patent application. 'Near science' patent applications are those that list at least one citation to the scientific literature. Source: Authors' calculations using PATSTAT (Oct 2009).

One possible concern is that these patterns are driven by differences in the composition of industries, that is, Chinese inventors might specialise in technologies that are more likely to cite the scientific literature. We find no evidence for this. While patent applications that list Chinese inventors are more likely to be classified into the Communications industry, which is one of the industries in which near science applications are more prevalent,²¹ the patterns

²⁰ The patterns shown in Figure 2 continue to hold if we instead consider the patent applications made by Chinese applicants. In 2005 a larger proportion of patent applications with Chinese applicants were near science (24%) than was the case for all EPO applications (12%) or those with US applicants (8%).

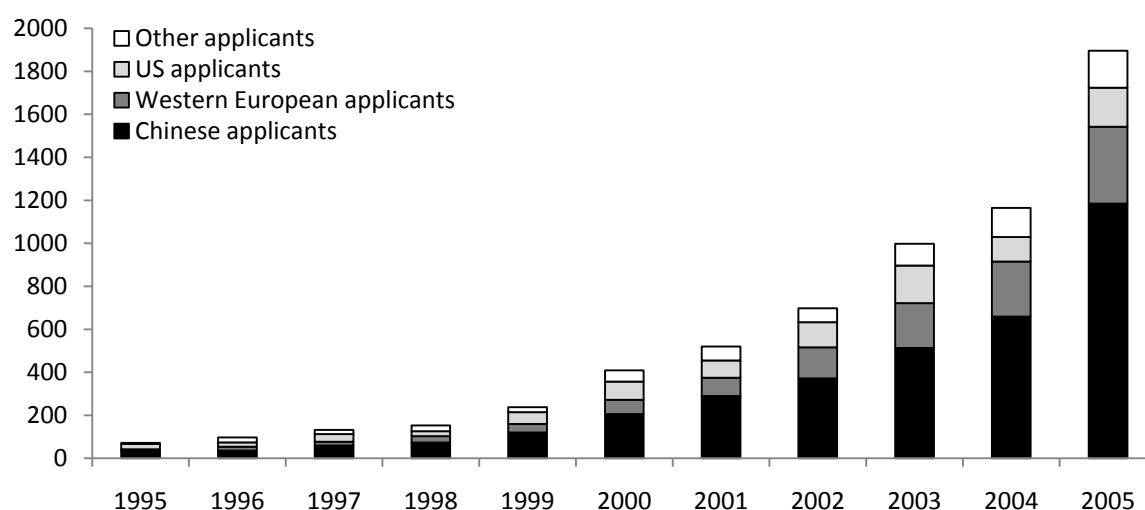
²¹ 29% of patent applications which list a Chinese inventor are listed on patent applications classified into the Communications industry, compared to 16% for all applications and for applications which list a US inventor. The proportion of all EPO applications that are near science for each of 6 industries is: Communications, 28%; Computing, 30%; Pharmaceuticals, 30%; Chemical, 24%; Electrical, 23%; Engineering, 15%.

described above hold both within the communications industry, and if communications patent applications are excluded.

4 European multinationals innovating in emerging economies

One important reason that China, and other emerging economies, have experienced an increase in innovation has been their success in attracting investment of foreign firms (Lundin and Schwaag Serger (2007)). The increase in the number of EPO patent applications which list at least one inventor in China, shown in Figure 3, is partially attributable to applicants from the US and Western Europe.

Figure 3: Number of EPO patent applications with at least one Chinese inventor, by applicant country



Notes: The data include all EPO patent applications. Each bar shows the number of patent applications with at least one Chinese inventor. Years refer to the application priority year of the patent application. Western European applicants are those from: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Switzerland and UK.

Source: Authors' calculations using PATSTAT (Oct 2009).

Western multinationals are increasingly conducting innovation in emerging economies, such as China (see, for example, UNCTAD (2005), Thursby and Thursby (2006) and Bruche (2009)). In a survey of 1,000 of the largest corporate R&D spenders covering 2004 to 2007, 83% of new R&D sites and 91% of increases in R&D staff were found to be located in China or India (Jaruzelski & Dehoff 2008).

We consider the extent to which Western European multinationals file patent applications that list Chinese inventors and, as a comparison, inventors located in India and Eastern

Europe.²² We consider all patent applications filed by Western European multinationals, including those filed by subsidiaries (applicants) outside of the home country.²³

Many (often smaller) firms conduct no innovation offshore – around 80% of patenting firms in Western Europe use only inventors in the headquarter country.²⁴ For those Western multinationals that do create patent applications using inventors based offshore, most inventors have historically been located in North America, Europe and Japan. In recent years there has been a notable trend towards using inventors in emerging economies such as China, India and Eastern Europe. Figure 4 shows the growth in the number of patent applications filed by Western European multinationals that list at least one inventor in China, India or Eastern Europe. We see that the growth in Western European firms filing patent applications created by Eastern European inventors started in the early 1990s.²⁵ Growth in patent applications created by Chinese inventors started later, in the early 2000s, but has seen faster growth. There has been relatively less growth in the number of patent applications created by Indian inventors.

The growth shown in Figure 4 has led to a substantial increase in the proportion of Western European multinationals' patent applications that list inventors located in China, Eastern Europe or India. Over the period 1991-1995 0.28% of patent applications listed an inventor based in one of these three emerging economies. This increased to 1.07% by the period 2001-2005.

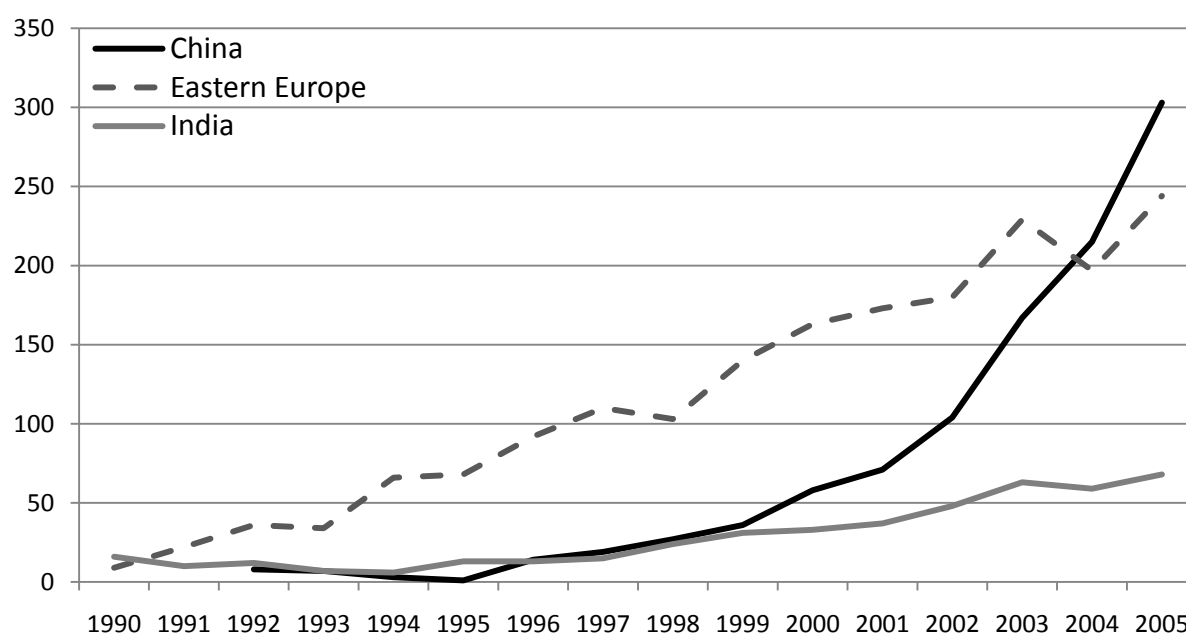
²² We define the group of Eastern European countries as follows: Belarus, Bulgaria, Czech Republic, Hungary, Latvia, Lithuania, Poland, Republic of Moldova, Romania, Russia, Slovakia, Ukraine Estonia.

²³ We use data EPO patent applications matched to firms' ownership structure from accounts data, which allows us to capture the fact that the applicants in the patent data may in fact be subsidiaries of large multinationals (a UK headquartered firm may file a patent application via an offshore subsidiary). The data includes information on the patenting activity of firms headquartered in fourteen Western European countries (listed in Table 1). For details, see Abramovsky et. al (2008).

²⁴ Figures are authors' calculations. Note that firms with no inventors offshore tend to file fewer patent applications; the 20% of firms with inventors offshore account for over 80% of patent applications.

²⁵ Both the number and growth of patent applications listing Eastern European inventors is accounted for predominately by Russia and Hungary, followed by the Czech Republic and Poland. This is supported by a 2008 survey of executives, which finds that majority of R&D labs set up in Central and Eastern Europe were located in one of the same four countries (Economist Intelligence Unit (2008)).

Figure 4: Number of EPO patent applications filed by Western European firms.



Notes: Each line is the number of EPO patent applications filed by a Western European firm or associated subsidiary that lists at least one inventor in the indicated country. Years refer to the application priority year. Source: Authors' calculations using PATSTAT (Oct 2009) matched to firms accounts data. See Abramovsky et. al. (2008).

Table 1 provides further details on the extent to which Western European multinationals filed patent applications listing inventors in emerging economies in the period 2001-2005. Columns (1) and (5) show the total number of firms and associated EPO patent applications respectively, by firms' headquarter country. Columns (2)-(4) show how many of the firms in column (1) hold at least one patent application with at least one inventor in the corresponding emerging economy. Similarly, columns (6)-(8) show the number of patent applications with at least one inventor in each emerging economy. Of the 21,409 firms in our data, 204 filed at least one patent application listing a Chinese inventor; together they filed 866 patent applications. Across the period 2001-2005 there are more firms and more associated patent applications which list an Eastern European than Chinese inventor. However, as indicated by Figure 4, patent applications listing Chinese inventors have become more prevalent in recent years. There are interesting differences across parent firms' headquarter countries. For example, French and Dutch firms are associated with relatively more patent applications that list Chinese inventors while German firms use Eastern European inventors more intensively.

It is notable from Table 1 that most firms file no patent applications which list inventors in emerging economies. To date the trend towards innovating in emerging economies, while pronounced, has been driven by a relatively small number of large multinationals (that account for the majority of European firms' patenting activities).

Table 1: Firms and patent applications listing inventors in Emerging Economies (2001-2005)

Headquarter country	Number of firms				Number of patent applications			
	with at least one patent application with at least one inventor in:				with at least one inventor in:			
	Total	China	Eastern Europe	India	Total	China	Eastern Europe	India
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<i>All</i>	<i>21409</i>	<i>204</i>	<i>558</i>	<i>129</i>	<i>201591</i>	<i>866</i>	<i>1031</i>	<i>276</i>
Belgium	501	8	24	8	4261	6	32	11
Denmark	657	6	16	2	4583	17	24	.
Finland	546	3	15	1	6203	88	63	6
France	2255	28	83	18	28172	181	115	39
Germany	6122	64	200	39	76718	195	392	98
Ireland	240	.	9	3	990	.	37	2
Italy	3200	4	26	2	10639	3	30	2
Luxembourg	49	3	5	1	772	1	5	3
Netherlands	1180	15	27	7	21570	185	66	61
Norway	404	1	6	.	1226	1	4	.
Spain	873	3	6	2	4193	3	6	4
Sweden	1077	10	31	6	10087	34	87	6
Switzerland	805	18	39	10	15017	96	97	18
UK	3500	41	71	30	17160	56	73	26

Notes: Column (1) records the number of firms headquartered in the given country that file at least one EPO patent application between 2001-2005. Patent applications include those filed directly by the parent firm and those filed by a subsidiary. Figures are for the application priority years 2001-2005.

Source: see Figure 4.

Table 2 provides detailed information on the six Western European firms that account for the largest number of Chinese inventors. For each firm column (1) records the total number of patent applications filed between 2001-2005 and columns (2)-(4) the number that had at least one inventor in China, Eastern Europe or India respectively. The first row shows information for the whole firm and the following rows for the two subsidiaries that hold the largest number of patent applications listing inventors China. For example, the first firm,

Philips Electronics, filed 11,436 patent applications, of which 155 had at least one Chinese inventor. The majority of patent applications are filed from the main home subsidiary and a significant number are filed from a large German subsidiary, Philips Intellectual Property & Standards.

Table 2: Top 5 Western European firms and subsidiaries (2001-2005)

		Number of patent applications with at least one inventor in:			
Firm		Total	China	Eastern Europe	India
Subsidiary		(1)	(2)	(3)	(4)
Koninklijke Philips Electronics	NL	11436	155	3	0
<i>Koninklijke Philips Electronics</i>	<i>NL</i>	<i>9780</i>	<i>154</i>	<i>1</i>	<i>0</i>
<i>Philips intellectual property and standards</i>	<i>DE</i>	<i>1361</i>	<i>1</i>	<i>1</i>	<i>0</i>
Siemens AG	DE	7739	36	29	11
<i>Patent-treuhand-gesellschaft</i>	<i>DE</i>	<i>407</i>	<i>19</i>	<i>0</i>	<i>0</i>
<i>Siemens AG</i>	<i>DE</i>	<i>6061</i>	<i>13</i>	<i>27</i>	<i>9</i>
Nokia corporation	FI	3705	88	50	6
<i>Nokia corporation</i>	<i>FI</i>	<i>3597</i>	<i>85</i>	<i>49</i>	<i>2</i>
<i>Nokia inc.</i>	<i>US</i>	<i>84</i>	<i>3</i>	<i>1</i>	<i>4</i>
BASF AG	DE	3505	49	4	2
<i>BASF SE</i>	<i>DE</i>	<i>2437</i>	<i>45</i>	<i>2</i>	<i>2</i>
<i>BASF AG & BASF coatings AG</i>	<i>DE</i>	<i>773</i>	<i>4</i>	<i>0</i>	<i>0</i>
Alcatel lucent	FR	2836	63	3	3
<i>Alcatel lucent & Alcatel</i>	<i>FR</i>	<i>2626</i>	<i>62</i>	<i>3</i>	<i>3</i>
<i>Tcl & Alcatel mobile phone ltd†</i>	<i>CN</i>	<i>17</i>	<i>1</i>	<i>0</i>	<i>0</i>
Thomson multimedia	FR	2354	94	1	19
<i>Thomson licensing</i>	<i>FR</i>	<i>2309</i>	<i>93</i>	<i>1</i>	<i>19</i>
<i>Nextream France</i>	<i>FR</i>	<i>13</i>	<i>1</i>	<i>0</i>	<i>0</i>

Notes: Firms are arranged in descending order of total EPO patent applications filed in 2001-2005. Names appear as in patents data. The first row shows information for the whole firm and the following rows for subsidiaries. Each patent application is counted once per firm. Countries are coded as follows: China (CN); Finland (FI); France (FR); Germany (DE); Netherlands (NL); US (US)

† TCL & Alcatel Mobile Phones Limited is a subsidiary of Alcatel based in China and set up jointly by TCL Communication Technology Holdings Limited (a Chinese firm) and Alcatel (a French firm) in 2004.

Source: see Figure 4.

4.1 European intellectual property

A striking feature of Table 2 is that, in cases where Western European firms hold patent applications listing inventors from emerging economies, the subsidiaries holding the intellectual property are most often located in the home country or another Western European country. That is, Western European firms are not holding the associated intellectual property in the emerging economy. We find that this pattern holds generally for Western European firms that file patents listing inventors in emerging economies.²⁶ As a point of contrast, we find that almost 40% of Western European multinationals' patent applications that list a US inventor are held in US subsidiaries.

Firms may hold intellectual property in European subsidiaries because the underlying technology is destined for European markets. Some firms will innovate in China in order to adapt products or processes to the local market, while others will source innovation that feeds into the production of technologies used in the West; recall, these are patent applications which are seeking intellectual property protection in European countries (via the EPO).²⁷ This view is consistent with the evidence that Chinese inventors are involved in creating new science, which then feeds into the production of European knowledge (rather than adapting products to the local market).

Firms may also hold intellectual property created in emerging economies in the West in order to circumvent weak intellectual property regimes in emerging economies. It has been well documented that intellectual property regimes in emerging economies are not as strong as those in Western Europe and the US (see, for example, Frietsch and Wang (2007)). The 2010 International Property Rights index (IPRI) - an annual study comparing countries property rights protection - showed that China and India both rank in the third quintile of the world intellectual property rights ranking; India ranks marginally higher.²⁸

²⁶ It is not only the large firms in Table 2 that hold the intellectual property associated with Chinese inventors in the west. Considering all patent applications with at least one inventor in China we find that 97.5% are held by a subsidiary in a Western European country, 2.4% held in a US subsidiary and fewer than 0.1% are held in a Chinese subsidiary. In contrast, when Western European firms hold patent applications listing US inventors, 37% are held in US subsidiaries.

²⁷ For discussion of firms motives for offshoring activity see, inter alia, OECD (2011), Dunning (1977), Cantwell and Mudambi (2000), Cantwell and Odile (1999), Belderbos, Lykogianni, Veugelers (2008), Veugelers and Cassiman (2004), Griffith, Harrison and Van Reenen (2006), Zedtwitz and Gassman (2002), Serapio and Dalton (1999).

²⁸ The Eastern European countries differ in the extent of protection offered by intellectual property rights; while Hungary, the Czech Republic and Poland all rank higher than India, Russia ranks much lower and is in the forth quintile. See Strokova (2010), The International Property Rights Index, 2010 report.

Zhao (2006) provides evidence that large multinational firms use internal mechanisms to protect their intellectual property, and thus overcome the market failure of poor institutions. Firms are able to exploit lower costs and other benefits of conducting research in locations with weaker intellectual property regimes by controlling the intellectual property from Western countries.

The propensity to hold intellectual property in the West, and in particular in firms' home countries, may be also related to the industries in which Chinese inventors are most often involved. Research has suggested that multinational firms commonly hold the intellectual property relating to information and communication technologies in the home country (Macher et al. 2007; Di Minin & Palmberg 2006).

4.2 Team work

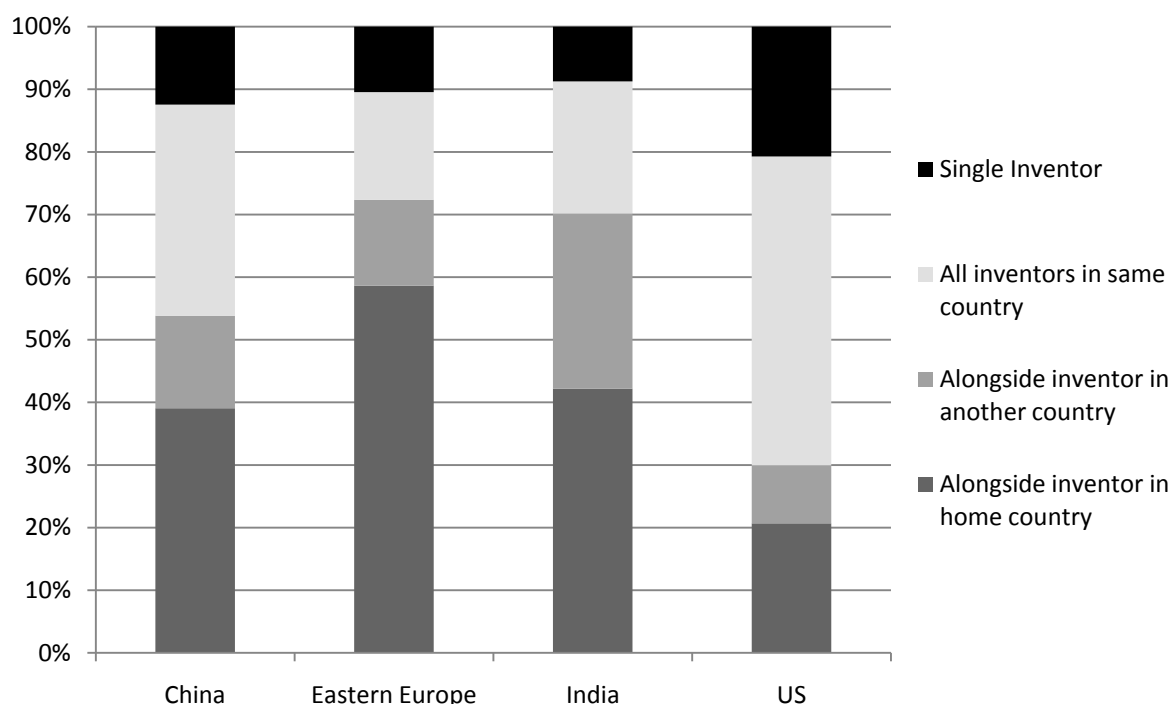
Patent applications listing inventors from emerging economies are more likely to be the result of team work, and the teams are more likely to include inventors from other countries, often the parent firms' home country, than is the case for patent applications created by inventors from the West. Previous research suggests that there may be benefits from combining Chinese inventors with those in the West in order to facilitate knowledge transfer. For example, Singh (2005), using patents data from the USPTO, finds that interpersonal networks (between inventors) are 'important in determining patterns of intraregional and intrafirm knowledge flows.'

Figure 5 shows proportion of patent applications that are produced by teams, and the composition of the teams. Each bar represents all patent applications that have at least one inventor located in the indicated country. The bottom three bars (in grey scale) show the proportion of patent applications that are produced by teams (i.e. by more than a single inventor). The top (black bar) shows inventors that are working alone.

In all countries the majority of patent applications are created by teams of inventors. This is supported by recent literature that has emphasised the increasing prevalence of team-based research as a consequence of increasing technological complexity. For example, Jones (2009) shows theoretical and empirical evidence that as technology has advanced, successive generations of innovators have faced an increasing burden - needing to spend longer in education and narrowing their field of expertise – which has lead to a greater

reliance on teamwork. Wuchty et al (2007) shows that for both published articles and patents held at the USPTO there has been an increasing trend towards multiple authors and inventors respectively since the 1970s.²⁹

Figure 5: Proportion of patent applications according to type of research team (2001-2005)



Notes: Figure includes all EPO patent applications filed by Western European firms with at least one inventor in indicated country. Each bar is split according to the proportion of patent applications in each category. The category 'Alongside inventor in another country' covers those cases where there is no inventor in the firm's home country but is an inventor outside of the country indicated by the bar title. Data are for 2001-2005.

Source: see Figure 4.

The bottom three bars (in grey scale) show the proportion of patent applications where the teams of inventors are all based in the same country or where they are collaborating with inventors in other countries. In the latter case we distinguish cases where there is an inventor in the firms' home country. We see that inventors from emerging economies are more likely to be working in teams and alongside inventors from the firms' home country than US inventors. Of the 88% of the patent applicants with at least one Chinese inventors that also list another inventor (i.e. are created with a team of inventors), 34% are comprised of all Chinese inventors, and 39% list an inventor from the firm's home country. For patent applications with at least one US inventor, 79% involve a team of inventors which includes

²⁹ Furman and Stern (2006) present evidence for the cumulative nature of knowledge and the importance of research-enhancing institutions (related to teamwork). Agrawal and Goldfarb (2008) show that decreases in the cost of collaborating have changed the structure of knowledge production and led to an increase in collaboration across institutions.

49% that are comprised of all US inventors, and 20% that list an inventor from the firm's home country. The proportion of applications that involve inventors working in teams is highest for patent applications with Eastern European inventors.

Considering how the prevalence and composition of research teams has changed over time, we find that inventors in Eastern Europe and India have become more likely to be working on international research teams. In contrast, there has been a marked decrease in the propensity of Chinese inventors to be working in international teams – Western European firms are creating more technologies which have been developed by only Chinese inventors and fewer that involve collaboration with inventors in the home country. In 1995-2000, of the patent applicants with at least one Chinese inventor, 3.25% were created by research teams comprised of all Chinese inventors (compared to 33.7% in 2001-2005) and 70.78% listed an inventor from the firm's home country (compared to 39.1% in 2001-2005).

It has been suggested in the literature that Chinese inventors are more likely to work in teams that include inventors from other countries because this is a mechanism used to control for inferior expertise. For example, Branstetter and Foley (2007) report that nearly half of US patents with Chinese inventors involved international teams and suggest that this may be the result of "China's raw engineering talent...requiring additional input from skilled researchers in more advanced countries in order to generate true innovation."³⁰

To address this we ask whether the type of science created differs depending on whether a research team is composed of all Chinese inventors, compared with when there are also inventors in the firm's home country. If teams are being used as a way to control for inferior expertise of inventors in emerging economies, we might expect that near science patent applications are more often created by an international research team than by teams composed on all Chinese inventors.

In Table 3 we show the team structure of all patent applications that list at least one Chinese inventor (on the left hand side), compared to that of patent applications that list at least one US inventor (on the right hand side). The top panel shows this for all patent applications that are near science, while the bottom panel includes those applications that do not cite the science base directly.

³⁰ For direct quote see <http://www.voxeu.org/index.php?q=node/710>

We find no compelling evidence that Chinese inventors are more likely to be working on teams or with inventors from firms' home countries when they are involved in creating patentable technologies that are near science.

Table 3: Type of activity and team structure (2001-2005)

Patent applications with at least one inventor in China		Patent applications with at least one inventor in US	
Near science applications			
All inventors in China	60	All inventors in US	67.3
<i>single inventor in China</i>	11.7	<i>single inventor in US</i>	18.8
<i>multiple inventors in China</i>	48.3	<i>multiple inventors in US</i>	48.5
Inventors in China and other:	40	Inventors in US and other:	32.7
<i>home country of firm</i>	29.7	<i>home country of firm</i>	21.8
<i>another country</i>	10.3	<i>another country</i>	10.9
	100%		100%
All other applications			
All inventors in China	43.4	All inventors in US	70.5
<i>single inventor in China</i>	12.6	<i>single inventor in US</i>	21.0
<i>multiple inventors in China</i>	30.8	<i>multiple inventors in US</i>	49.5
Inventors in China and other:	55.6	Inventors in US and other:	29.5
<i>home country of firm</i>	41.0	<i>home country of firm</i>	20.5
<i>another country</i>	15.6	<i>another country</i>	9.0
	100%		100%

Notes: The sample includes EPO patent applications filed by Western European firms between 2001/2005 with at least one inventor in China (left hand column) or the US (right hand column). 'Near science' patent applications are those that list at least one citation to the scientific literature.

Source: see Figure 4.

When creating near-science technologies Chinese inventors are slightly less likely than US inventors to be working alone (11.7% of near science applications list a single Chinese inventor; 18.8 list a single US inventor) and slightly more likely to be collaborating with inventors in the country of the parent firms' headquarters (29.7% of near science applications list inventors in China and the firm's home country; the equivalent figure for the US is 21.8%). In contrast, the team structure of patent applications that do not cite the scientific literature differs markedly between China and the US. In this case Chinese inventors are much more likely to be working in a team (especially one which includes an inventor in the firms' home country).

We also see that for patent applications that list a Chinese inventor, a smaller proportion of near science patent applications list inventors in other countries (40%) than is the case for

all other applications (55.6%) – the reverse is true for patent applications which list a US inventor. The finding that Chinese inventors are not more likely to be working on international research teams when creating near science technologies goes against suggestions that other inventors are compensating for inferior skills.

5 Conclusions

If current trends continue we could see Chinese applicants filing as many patent applications as US applicants as soon as 2015. It seems likely that the rapid growth in Chinese innovation will continue in the near future as the increased investment in skills continues to translate into outputs. This alone does not constitute evidence that China will rival the West in the creation of new technologies. Not all patent applications are created equal and a long understood drawback of using patent statistics is that the value of patents is highly heterogeneous. Much of the academic literature to date has argued that Chinese innovation most often represents only an incremental advance on previous work, rather than producing innovations which are new to science.

In this paper we use information on patent applications filed at the European Patent Office, and find that the proportion of patent applications created by Chinese inventors that cite the scientific literature – which we use as an indication of an innovation that stems from more fundamental research that is close to the science base – is at least as high as the proportion which is created in the West. That is, Chinese inventors display the capacity to innovate alongside US and European inventors at the technology frontier.

Part of the success of China and other emerging economies has been in attracting the investment of Western European firms. The continuing investments in research capacity and improvements in institutions should work to support increased foreign investment.

An area where there continues to be important institutional improvements is the protection of intellectual property rights. In recent years the intellectual property rights regimes have improved in China and many of the Eastern European countries.³¹ Such changes, as well as being important for economic growth in general (Acemoglu et al (2005)), are likely to affect

³¹ The 2010 International Property Rights index shows that China saw one of the biggest improvements in the score capturing intellectual property rights protection (Table 5, Strokova (2010)). Some Eastern European countries, notably the Czech Republic, also saw improvements while India saw a small decline. See also Maskus (2000). Many of the improvements in China's property rights occurred following accession to the World Trade Organisation (WTO) in 2001 (Maskus (2004)).

both the level of investment in intellectual property by foreign firms and the type of innovations that are created. Javorcik (2004) considers how the composition of foreign direct investment in Eastern Europe during the 1990s related to country differences in intellectual property rights regimes, finding that weak protection deter foreign investors in technology-intensive sectors. Mansfield (1994) reports evidence that the strength of intellectual property protection affects both the kinds of technology transferred by U.S. firms to an emerging economy and the overall extent of U.S. direct investment to such countries. Branstetter, Fisman and Foley (2006) show that U.S. multinationals respond to changes in IP regimes abroad by significantly increasing technology transfer to reforming countries. Belderbos (2006) presents direct evidence that multinationals from the US, Europe and Japan created more patent applications in Asian economies that have strong intellectual property rights regimes. One might therefore expect firms to increasingly see emerging economies as locations for technological sophisticated innovations as reforms continue to provide greater intellectual property rights protection.

Given these trends, concerns over Western economies' ability to maintain their dominance in knowledge creation and high skill employment are perhaps unsurprising. Innovation has been the engine of economic growth, and lies at the heart of increased living standards. However, there are many reasons why these trends are not necessarily bad news for the West.

Firms locating activity offshore, either to adapt products to local markets or gain access to specific skilled workers or localised technologies, potentially at lower cost, can lead to standard gains from trade, both directly through improved performance and indirectly if knowledge is transmitted back to the home country.³² Emerging economies also represent new markets for goods and services developed in Western European economies.

Of course, there are important benefits from having activity located in Western economies. Most directly, Western governments are justifiably keen to encourage high skilled employment. Countries also benefit from the creation of innovations indirectly in the form of spillovers – the knowledge which accrues to third parties. Such spillovers are often geographically concentrated because researchers that work in close proximity are more

³² This idea is similar to the argument that there are gains from increased trade in goods and manufacturing in a world with differentiated inputs, where different countries produce different inputs. See, for example, a recent article by Amiti and Konings (2007). See also, Griffith, Redding, and Van Reenen (2004).

likely to interact and share tacit knowledge. However, there is evidence that knowledge flows across national borders (Branstetter (2006), Iwasi and Odagiri (2004) and Singh (2006)) and that knowledge is less restricted by distance than was the case 20 years ago (Griffith, Lee and Van Reenen (2011)).

It is also the case that innovation is not a zero sum game – that more research is being carried out in China does not imply that less will be undertaken in the West. Abramovsky, Griffith and Miller (2011) directly consider the impact of firms increasing offshore inventors on the number of inventors located in the home country and find no evidence of a negative effect. Indeed, it might be expected that there are more synergies in the creation of new technologies than new goods or services such that an increase in knowledge output in China compliments, rather than substitutes for, knowledge created in the West.

The challenges for Western governments may not relate to devising policies to deter investment in emerging economies, but to fostering a highly skilled workforce that is able to both compete for and engage collaboratively in tomorrow's breakthroughs and that is flexible enough to adjust to changing conditions.

6 References

- Abramovsky, L., R. Griffith, G. Macartney, and H. Miller (2008), "The location of innovative activity in Europe" IFS Working Paper W08/10
- Abramovsky, L., R. Griffith, and H. Miller (2011), "Offshoring high-skilled jobs: EU multinationals and domestic employment of inventors" IFS mimeo
- Acemoglu, D., S. Johnson, J. Robinson (2005), "Institutions as the Fundamental Cause of Long-Run Growth" in Aghion, P. and S. Durlauf (eds.) *Handbook of Economic Growth*.
- Agrawal, A. And Goldfarb, A. (2008), "Restructuring Research: Communication Costs and the Democratization of University Innovation," *American Economic Review*, vol. 98(4), pages 1578-90, September.
- Amiti, M. And Konings, J. (2007) "Trade Liberalization, Intermediate Inputs, and Productivity: Evidence from Indonesia," *American Economic Review*, vol. 97(5), pages 1611-1638, December.
- Belderbos, R. (2006), "R&D activities in East Asia by Japanese, European, and US multinationals" JCER discussion paper, 100
- Belderbos, R., E. Lykogianni and R. Veugelers (2008) "Strategic R&D Location in European Manufacturing Industries," *Review of World Economics*, vol. 144(2), pp 183-206, July.
- Bernard, A., B. Jensen and P. Schott (2006), ""Survival of the Best Fit: Exposure to low-wage countries and the (uneven) growth of US manufacturing establishments" *The Journal of International Economics*, 68(1), 219-237
- Bloom N., M. Draca and J. Van Reenen (2008), "Trade induced technical change? The impact of Chinese imports on technology and employment" LSE mimeo

- Branstetter, L., R. Fisman and F. Foley (2006) "Do Stronger Intellectual Property Rights Increase International Technology Transfer? Empirical Evidence From U.S. Firm-Level Panel Data," *Quarterly Journal of Economics*, v121 (1, Feb), 321-349.
- Branstetter and Foley (2007) "Facts and fallacies about U.S. FDI in China", in Feenstra, R. and S. Wei (eds.) *China's Growing Role in World Trade* University of Chicago Press
- Bruche, G. (2009), "The Emergence of China and India as New Competitors in MNCs' Innovation Networks", *Competition & Change*, Vol 13 (3), pp. 267-288(22)
- Cantwell, J. and R. Mudambi (2000) "The Location of MNE R&D Activity: The Role of Investment Incentives" *Management International Review*, 40(1): 127-148
- Cantwell, J. and J. Odile (1999) "Technological globalisation and innovative centres: the role of corporate technological leadership and locational hierarchy," *Research Policy*, Elsevier, vol. 28(2-3), pages 119-144, March
- Carstensen, K. and F. Toubal (2004) "Foreign direct investment in Central and Eastern European countries: a dynamic panel analysis" *Journal of Comparative Economics* Vol 32, Issue 1, March 2004, Pages 3-22
- Chen, Y.-C. (2007), "The upgrading of multinational regional innovation networks in China", *Asia Pacific Business Review*, 13(3): 373-403.
- Di Minin, A. and Palmberg, C. (2006), "A Case for Non-globalization? The Organization of R&D in the Wireless Telecommunications Industry", Brie Working Paper 176 (Berkeley: Roundtable on the International Economy, University of California).
- Dunning, J. (1977) "Trade, location of economic activity and MNE: a search for an eclectic approach" in Ohlin, B., Hesselborn, P.O., Wijkman, P.M. (eds.), *The International Allocation of Economic Activity*, McMillan, London, pp. 395-418.
- Ernst and Young (2010) "Waking up to the new economy", 2010 European attractiveness survey
- Eaton, J., S. Kortum and J. Lerner (2004) "International Patenting and the European Patent Office: A Quantitative Assessment" Chapter 1 in *Patents, Innovation and Economic Performance*, OECD
- Economist (2010), "A special report on innovation in emerging markets", Apr 15th 2010.
- Economist Intelligence Unit (2008) "A time for new ideas Innovation in Central Eastern Europe and Turkey", A white paper by the Economist Intelligence Unit.
- European Commission (2009) "The World in 2025, Rising Asia and socio-ecological transition", ISBN: 978-92-79-12485-3.
- Feenstra, R. and S. Wei (2009) "Introduction to 'China's Growing Role in World Trade'" in Feenstra, R. and S. Wei (eds.) *China's Growing Role in World Trade*, University of Chicago Press
- Freeman, R. (1995), "Are your wages set in Beijing?" *Journal of Economic Perspectives*, 9 (3), 15-32
- Freeman, R. (2006), "Does Globalization of the Scientific/Engineering Workforce Threaten US Economic Leadership" in Jaffe, Lerner and Stern (eds) *Innovation Policy and the Economy*, Vol 6, MIT Press
- Freeman, R. (2009), "What does global expansion of higher education mean for the us?" NBER Working Paper 14962
- Frietsch, R. and J. Wang (2007), "Intellectual Property Rights and Innovation Activities in China: Evidence from Patents and Publications"
- Furman, J. and S. Stern (2006) "Climbing Atop the Shoulders of Giants: The Impact of Institutions on Cumulative Research" *NBER Working Paper 12523*.

- Griffith, R., R. Harrison, and J. Van Reenen (2006) "How Special Is the Special Relationship? Using the Impact of US R&D Spillovers on US Firms as a Test of Technology Sourcing" *American Economic Review*, vol 96, No 5, 1859-1875
- Griffith, R., Lee, S., Van Reenen, J. (2011) Is distance dying at last? Falling home bias in fixed effects models of patent citations, *Quantitative Economics*, forthcoming
- Griffith, R. and G. Macartney (2010) "Employment protection legislation, multinational firms and innovation" *IFS Working Papers* W10/01
- Griffith, R., S. Redding, and J. Van Reenen (2004), "Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries" *Review of Economics and Statistics*, 86(4): 883-95
- Griliches, Z. (1990) "Patent Statistics as Economic Indicators: A Survey," *Journal of Economic Literature*, American Economic Association, vol. 28(4), pages 1661-1707, December.
- Guellec, D. and B. van Pottelsberghe de la Potterie (2007), "The economics of the European patent system", Oxford University Press, Oxford,
- Iwasa, T., and H. Odagiri (2004), "Overseas R&D, Knowledge Sourcing, and Patenting: An Empirical Study of Japanese R&D Investment in the US." *Research Policy*, 33(5): 807-28
- Jaffe, A. and Lerner, J. (2004) "Innovation and its discontents – How our broken patent system is endangering innovation and progress, and what to do about it", Princeton University Press, Princeton and Oxford.
- Jaffe, A., M. Trajtenberg (2002) "Patents, Citations and Innovations: A Window on the Knowledge Economy" MIT Press, Cambridge, MA.
- Jaffe, A., M. Trajtenberg and R. Henderson (1993), "Geographic localization of knowledge spillovers as evidenced by patent citations", *Quarterly Journal of Economics* 108 (3), pp 577-598
- Jaruzelski, B. and Dehoff, K. (2008), "Beyond borders: the global innovation 1000", *Strategy+business*, 53: 54–67.
- Javorcik, B. (2004), "The Composition of Foreign Direct Investment and Protection of Intellectual Property Rights: Evidence from Transition Economies," *European Economic Review* 48: 39 – 62
- Jones, B. (2009) "The Burden of Knowledge and the "Death of the Renaissance Man": Is Innovation Getting Harder?" *Review of Economic Studies* 76, 283–317
- Khan, M. and H. Dernis (2005), "Impact of Patent Co-Operation Treaty Data on EPO Patent Statistics and Improving the Timeliness of EPO Indicators", *OECD Science, Technology and Industry Working Papers*, 2005/2
- Li, H., B. Fraumeni, Z. Liu and X. Wang (2009) "Human Capital in China" NBER Working Paper 15500
- Li, Y., J. Whalley, S. Zhang and X. Zhao (2008) "The Higher Educational Transformation of China and Its Global Implications" NBER Working Paper 13849
- Liu, R. and D. Treffer (2008) "Much Ado About Nothing: American Jobs and the Rise of Service Outsourcing to China and India" NBER Working Paper 14061
- Lundin, N. and S. Schwaag Serger (2007) "Globalization of R&D in China - Empirical Observations and Policy Implications" *Institute of Industrial Economics Working Paper Series* 710
- Macher, J.T., Mowery, D.C. and Di Minin, A. (2007), "The 'non-globalization' of innovation in the semiconductor industry", *California Management Review*, 50(1): 217–242.

- Mansfield, E. (1994) "Intellectual Property Protection, Foreign Direct Investment, and Technology Transfer" International Finance Corporation, Discussion Paper 19, The World Bank.
- Marin, D. (2006) "A New International Division of Labor in Europe: Outsourcing and Offshoring to Eastern Europe," *Journal of the European Economic Association*, 4(2-3), 612-622.
- Maskus, K. (2000) "Intellectual Property Rights in the Global Economy" Washington, DC: Institute for International Economics
- Maskus, K. (2004) "Intellectual property rights in the WTO Accession Package: assessing China's response" in Bhattasali, D., S. Li and W. Martin (eds.) China and the WTO: accession, policy reform, and poverty reduction strategies, The World Bank
- Medcof, J.W. (2007) "Subsidiary technology upgrading and international technology transfer, with reference to China", *Asia Pacific Business Review*, 13(3): 451-470.
- OECD (2008a), Globalisation and Emerging Economies; Brazil, Russia, India, Indonesia, China and South Africa, OECD Publishing
- OECD (2008b), "Reviews of Innovation Policy: CHINA", OECD Publishing.
- OECD (2010), OECD Science, Technology and Industry Outlook, OECD Publishing.
- OECD (2011), "Attractiveness for Innovation: Location Factors for International Investment", OECD Publishing.
- Puga, D. and D. Trefler (2010) "Wake up and smell the ginseng: International trade and the rise of incremental innovation in low-wage countries", *Journal of Development Economics* vol. 91(1), pages 64-76, January.
- Rodrik, D. (2006) "What's so special about china's exports?" NBER Working Paper 11947 and China & World Economy, Institute of World Economics and Politics, Chinese Academy of Social Sciences 14, 5 (2006) 1-19
- Schott, P. (2008) "The relative sophistication of Chinese exports" *Economic Policy*, Vol 23, Issue 53, 5-49
- Schwaag Serger, S. (2007) "Globalization of R&D and China", IFN Working Paper No. 710 (Stockholm: Research Institute of Industrial Economics).
- Serapio, M., Jr., and D. Dalton (1999), "Globalization of Industrial R&D: An Examination of Foreign Direct Investments in R&D in the United States." *Research Policy*, 28(2-3): 303-16
- Shukla, R. (2005), "India Science Report", National Council of Applied Economic Research (NCAER) <http://www.insaindia.org/India%20Science%20report-Main.pdf>
- Singh, J. (2005). Collaborative networks as determinants of knowledge diffusion patterns. *Management Sci.* 51(5) 756-770.
- Soete, L. (2009), "Malthus' Revenge", UNU-MERIT Working Paper 2009-030
- Stevnsborg, N. and B. van Pottelsberghe de la Potterie (2007), "Patenting procedures and filing strategies", in Guellec, D. and B. van Pottelsberghe de la Potterie (eds.), *The economics of the European patent system*, Oxford University Press, pp. 155-183.
- Stroková, V. (2010) "International Property Rights Index, 2010 report", available at www.internationalpropertyrightsindex.com
- Sun, Y., Du, D. and Li, H. (2006), "Foreign R&D in developing countries: empirical evidence from Shanghai", *China, China Review*, 6(1): 67-91.
- Thursby, J. and M. Thursby (2006) "Where Is the New Science in Corporate R&D?" *Science*, Vol 314, 8 December 2008, 1547-1548

- UNCTAD (2005), "World Investment Report 2005: Transnational Corporations and the Internationalization of R&D" (New York and Geneva: United Nations).
- van Pottelsberghe, B. (2008), "Europe's R&D: missing the wrong targets?", Brugel policy brief, issue 2008/3,
- Veugelers, R. and B. Cassiman (2004) "Foreign subsidiaries as a channel of international technology diffusion: Some direct firm level evidence from Belgium," *European Economic Review*, Elsevier, vol. 48(2), pages 455-476, April.
- von Zedtwitz, M., and O. Gassmann (2002) "Market versus Technology Drive in R&D Internationalization: Four Different Patterns of Managing Research and Development" *Research Policy*, 31(4): 569- 88
- Wang, Z. and S. Wei (2008) "What Accounts for the Rising Sophistication of China's Exports?" NBER Working Paper 13771
- Wuchty, S., B. Jones and B. Uzzi (2007) "The increasing dominance of teams in production of knowledge" *Science* May 18 2007
- Zhao, M. (2006) "Conducting R&D in Countries with Weak Intellectual Property Rights Protection", *Management Science*, Vol. 52, 1185-1199
- Zhou, P. and L. Leydesdorff (2006) "The emergence of China as a leading nation in science", *Research Policy* 35, 83–104.
- Wilsdon, J. and Keeley, J. (2007), "China: The next science superpower?", DEMOS report, 2007, ISBN1841801739.
- WIPO (2009) *World Intellectual Property Indicators*, WIPO Publication No. 941(E), ISBN 978-92-805-1869-6
- WIPO (2010) *World Intellectual Property Indicators*, WIPO Publication No. 941(E) ISBN 978-92-805-1978-5