From "Made in China" to "Innovated in China": Necessity, Prospect, and Challenges

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ABSTRACT

After more than three decades of high growth that was based on an exploration of its low-wage advantage and a relatively favorable demographic pattern in combination with market-oriented reforms and openness to the world economy, China is at a crossroad with a much higher wage and a shrinking work force. Future growth by necessity would have to depend more on its ability to generate productivity increase, and domestic innovation will be an important part of it. In this paper, we assess the likelihood that China can make the necessary transition. Using data on expenditure on research and development, and patent applications, receipts, and citations, we show that the Chinese economy has become increasingly innovative. In terms of drivers of innovation growth, we find that embracing expanded market opportunities in the world economy and responding to rising labor costs are two leading contributing factors. On the other hand, we find evidence of resource misallocation in the innovation area: while state-owned firms receive more subsidies, private firms exhibit more innovation results. Innovation can presumably progress even faster if resource misallocation can be tackled.

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1. Introduction

From 1980–2015, China's economy grew at an average annual rate of 8.7 percent. During these 35 years, real per capita income increased by a cumulative rate of 1759 percent, from $714 in 1980 to $13,277 in 2015 (based on the IMF's World Economic Outlook data, expressed in 2011 international purchasing power parity dollars). Apart from Equatorial Guinea, a country of less than a million people that literally struck oil, no other economy grew as much during the same period. China's growth performance is clearly spectacular and exceptional.

But China's economy has reached a crossroad. The annual growth rate has slowed to about 6–7 percent since 2013 and will likely moderate further. Part of the reason for the slowdown could be cyclical, a result of a relatively weak world economy. But a major part of the reason is structural and fundamental. China's economic growth of the previous three and a half decades was based on several key factors: a sequence of market-oriented institutional reforms, including openness to international trade and direct investment, combined with low wages and a favorable demographic structure. Chinese wages are now higher than a majority of non-OECD economies. For example, China's wages are almost three times as high as India, an economy with almost the same-sized labor force. The Chinese working age cohort has been shrinking since 2012.

The first section of this paper will review what factors have propelled China's economic growth in the past, and explain why they are unlikely to provide the same kind of boost going forward.

Future growth in China has to come mostly from the growth of labor productivity. Since China's investment-to-GDP ratio was already a remarkable 43.3 percent in 2015, it is hard to expect a high growth rate of productivity from continued physical investment. Indeed, Bai and Zhang (2014) estimated that the returns to investment have shown signs of decline since 2008. Some productivity increase could come from reducing resource misallocation (Hsieh and Klenow 2009), which could be accomplished by further reforms in the factor and product markets, including reforms of state-owned enterprises. However, the pace of reform in the future is unlikely to be as aggressive as in the past, partly because interest groups across China now have more means to block reforms than in the past and partly because the low-hanging fruit in the area of institutional reforms has been picked. Thus, productivity growth from this source also faces a limit.

Since the onset of the global financial crisis in 2008, the external demand for Chinese products has weakened, and wages in Chinese have meanwhile increased faster than almost all other major economies. A growth model based on exploiting the use of cheaper labor is no longer viable. While a strict family planning policy implemented since the early 1980s once produced an unnaturally low birth rate and therefore an unusually favorable dependence ratio for China, the same force has now produced relatively few people entering the labor force today relative to the new retirees, hence yielding an unusually unfavorable dependence ratio.

Facing rising labor costs and weak external demand, China's firms have to make a tough choice: in, out, up, or down. "In" is to move factories to inland areas where the wage is lower than coastal China. Given the pace of convergence within the country and the cost of logistics facing firms in the inland, this is at best a temporary strategy. “Out” means engaging in outbound direct investment, combining Chinese know-how with low wages in other countries. “Up” means innovation and upgrading, so that the firms no longer need to depend on low-paying unskilled labor. “Down” means closing the business; it is an option for individual firms, but not for the country as a whole. While a portfolio of these strategies will be employed by firms, a decisive factor for China’s economic future is whether its firms can innovate and upgrade and how fast they can do so. In the next section, we focus on innovation and quality upgrading, and ask the question: is China investing enough and wisely in research and development, and can it transition to a more innovative economy?

We study three questions in particular. First, how strong is China’s national investment in research and development (R&D)? We do so by comparing the Chinese trajectory in recent years with international experiences.

Second, what is the growth of innovation by Chinese firms? To answer this question, we make use of data on patents from China State Intellectual Property Office (SIPO), the United States Patent and Trademark Office (USPTO), and World Intellectual Property Office (WIPO). We use the data on patents to compare China’s rate of innovation as compared to other BRICS (that is, Brazil, Russia, India, and South Africa) economies and high-income economies (such as the United States, Germany, Japan, and the Republic of Korea). We will use patent applications and patents granted by firms both at home and in the United States as proxy for innovative activities. China’s performance on innovative activities as measured by patent data has been strong, especially in recent years, but China may well have some lessons to learn from India and in particular from the Republic of Korea. We will argue that rising wages and expanding markets are among the important drivers behind China’s patent explosion.

Third, because the Chinese economy continues to have a non-trivial share of state-owned enterprises, we investigate possible resource misallocation in the innovation space. Although state-owned enterprises have received more subsidies from the government, their performance in innovation is lackluster compared to private enterprises. Furthermore, the elasticity of patent filing or patents granted with respect to expenditures on research and development is significantly higher for private sector firms than for state-owned enterprises. We interpret these data patterns as existence of misallocations in public fiscal resources. Interestingly, we find that China’s state-owned enterprises often face higher realized tax burdens (the sum of corporate income tax and value added tax as a share of sales or value added). Leveling the playing fields for firms across all ownership, with simultaneous reductions in discretionary subsidies and taxes, would improve resource allocation.

2. Sources of China’s Growth since 1980 and the Moderation of Growth since 2012

China’s rapid growth in the past several decades has been driven by a combination of two sets of factors: a) market-oriented policy reforms to let market-determined output prices and factor prices replace administrative prices, to introduce and strengthen property rights, and to reduce barriers to international trade and investment; and b) economic fundamentals, including in particular a favorable demographic structure and a low initial level of labor cost. Here, we offer an overview of these factors and how they have evolved in the last 36 years.

The Chinese growth miracle started with the rural sector reform known as the "rural household responsibility system" in the early 1980s. Instead of collective farming and selling all output to a national procurement plan at a price set by the plan (usually substantially below the would-be market price), farmers were granted land user rights and allowed to sell what they produced in excess of the official quota at a market price. Agricultural production and rural incomes witnessed a dramatic increase in the ensuing years (Lin 1992). In a few years, hundreds of millions of farmers were released from their land and many started to work in factories, providing the nonfarm sector with a seemingly unlimited labor supply. In the 1980s, China's labor cost was among the lowest in developing countries, lower than in India and the Philippines and indeed lower than 114 out of 138 non-OECD economies. The vast majority of these workers were restricted to living in rural areas by the *hukou* system, with many working during the 1980s for township and village-owned enterprises, which were manufacturing firms located in rural areas. These enterprises provided a way for a reallocation of labor from low-productivity farm activities to higher-productivity manufacturing activities, at a time before restrictions on internal migrations were relaxed.

During the 1990s, the government launched reforms of township and village enterprises and of the state-owned enterprise sector. Most of the township and village enterprises were privatized, *de jure* or *de facto*. By 2011, the township and village enterprise sector had almost disappeared, with employment plummeting from 129 million in 1995 to merely 6 million in 2011 (Xu and Zhang 2009). Among state-owned enterprises, which were overwhelmingly in urban areas, employment fell by about half from 113 million in 1995 to 67 million in 2011. The number of state-owned firms declined from 1,084,433 (or 24 percent of the total number of firms) in 1995 to 521,503 (or 3 percent of the total) in 2014 (according to our tabulations based on the China Firm Registry database in Table 1). The much larger drop in the number of state-owned enterprises than in their employment was part of a deliberate policy of "grasping the large and letting go of the small"—that is, privatizing small state-owned enterprises and consolidating bigger ones (Hsieh and Song 2015).

The reform was painful in the short run, in that tens of millions of urban workers had to leave their former state-owned employers. Remarkably, the country avoided a big spike in the unemployment rate. The key is that the de facto privatization was accompanied by aggressive reforms to lower entry barriers faced by private sector entrepreneurs. The inefficiency of the previous centrally planned, state-dominated economic system, together with very high barriers to entry, meant huge unexplored or under-explored profitable opportunities. As a result, almost all of the lost jobs in township and village enterprises and state-owned enterprises were offset by new job opportunities in the dynamic private sector. The number of private enterprises increased by nearly five-fold to about 17 million in the period 1995–2014, as shown in Table 1. By 2011, 193 million people worked in private enterprises (including self-employed) (CNBS 2012). This represents the largest *de facto* privatization program in the world history in terms of the number of workers who move from state-sector to private sector employment, and one that was done without massive unemployment.

Through this period, the growth in the Chinese economy has become driven overwhelmingly by the growth in the private sector aided by an expansion in the number of entrepreneurs. This pattern is especially true for the manufacturing sector, which has been growing faster than either the agricultural or service sectors. Indeed, Wei and Zhang (2011b) have documented two "70 percent rules" using manufacturing firm census data in 1994 and 2005: First, approximately 70 percent of the growth in industrial value-added came from private sector firms between these two census years. Second, approximately 70 percent of private sector growth in value-added came from growth in the count of new private sector firms (the extensive margin), while the remaining 30 percent came from growth of existing firms (the intensive margin).

China also carried out a number of other reforms intended to incentivize local governments to pursue growth-friendly policies. For example, under the fiscal arrangement introduced in the early 1980s, local governments and the central government follow a pre-determined revenue formula (though varying across regions as a function of local bargaining power), which stimulates the incentives of local officials to create a more business-friendly environment. More generally, in spite of the political centralization by the Communist Party, the country has implemented a system of fiscal and economic decentralization that grants local governments sufficient decision-making power—and more importantly incentives— to compete with each other. Local economic growth rate is used as a key performance indicator for the career advancement of officials. The delegation of economic policy authority to local governments, which have better knowledge of local information, and competition for investment and tax base among local governments in the Chinese style of federalism have provided a useful check on the temptation of local government officials to expropriate local firms. As a result, firms acquire some *de facto* security of property rights, even if the formal property rights institutions are problematic (Qian and Weingast 1997; Xu 2011).

China's government also set up numerous special economic zones and special development zones in the coastal provinces to attract foreign direct investment in the 1980s and 1990s. These zones help the government to meet two challenges. First, public funding for infrastructure was limited, especially in the early days of the reform era. The government was able to concentrate limited public funding to provide adequate roads, power supply, waste treatment and other infrastructure to the firms within the zones, even when it was not able to improve the infrastructure nationally at the same speed. Second, policy reforms within these zones were politically easier than doing the same things on a national scale. The success in these zones in terms of economic growth, employment, and tax revenues in turn facilitated similar market-oriented reforms outside the zones. Foreign direct investment rose rapidly in China, especially since 1992, and these zones played an important role in attracting international firms.

Foreign-invested firms were and continue to be an important channel for transfer of technology and management ideas from advanced economies to China.

China's integration with the global economy was accelerated after the country joined the World Trade Organization in December 2001. Foreign-invested firms have often accounted for half of the country's total exports. China's trade expanded fast: While China's GDP approximately doubled once every seven years, its export value in US dollar terms doubled once every four years. By 2004, China had come to be known as the World Factory, a label describing not only the sheer volume of its cross-border trade, but also the breadth of its sector coverage (as discussed in Feenstra and Wei 2010). China's growth in both imports and exports, along with foreign investment coming to the country, is also an important channel for domestic firms to acquire technological knowhow.

While the deep cause of growth and development is institutional changes engendered by policy reforms and embrace of globalization, the proximate drivers of economic growth include improvement in productivity as a crucial component. The increase in productivity stems from innovations within sectors and the reallocation of resources (mainly workers) from lower-productivity to higher-productivity sectors, such as from the state sector to the private sector and from the agricultural sector to non-agricultural sectors (Zhu 2012). Sectoral productivity and structural change accounted for 42 and 17 percent of economic growth during 1978–1995 (Fan et al. 2003).

For three decades following the start of market-oriented reforms, China appeared to have an inexhaustible amount of "surplus labor" (which can be thought of as conceptually the same as low productivity labor in rural areas). But signs of labor shortage started to emerge in the first decade of the 2000s. According to Cai and Du (2011) and Zhang et al. (2011), wages for unskilled workers showed double digit growth starting in 2003-2004. The exact timing of a sharp increase in the wage rate of unskilled workers is subject to debate. Wang et al. (2011) report a turning point as early as 2000. On the other hand, Knight et al. (2011) and Golley and Meng (2011), for example, point out that barriers to internal migration, especially a rigid household registration system that prevents rural households from moving freely to urban areas, imply additional scope for rural-to-urban migration if and when the remaining barriers can be dismantled. In any case, China is a low-wage country no more.

Two features of demographic transition have also been a powerful driver of China's growth in the past three and a half decades. The first feature is a favorable dependence ratio. China's sharp decline in fertility rate has meant fewer young dependents to support for a given size of the working cohort. The fraction of prime-age population in total population rose steadily for three decades, creating an unusually large demographic dividend, which in turn contributed to economic growth (Cai and Wang 2008; Wei 2015).

The second feature of demography that affects growth is the gender ratio imbalance of the pre-marital cohort. This less-studied factor may have a quantitatively significant effect as well. The one-child policy has yielded an unintended consequence in distorting the sex ratio in favor of boys. As the one-child generation enters the marriageable age, young men face a very competitive marriage market. In order to attract potential brides, families with sons choose to work harder, save more, and take on more risks, including exhibiting a higher propensity to be entrepreneurs (Wei and Zhang 2011a and 2011b; Chang and Zhang 2015; Wei, Zhang, and Liu 2016). It is estimated that increasing marriage market competition due to sex ratio imbalances has contributed to about two percentage points of economic growth per year (Wei and Zhang 2011b).

It is important to point out that the additional growth due to an unbalanced sex ratio is of an immiserizing type: social welfare is likely to have become lower even though the GDP growth accelerated. The logic is explained in Wei and Zhang (2011b): the extra work effort and extra risk-taking that produce a higher GDP growth rate are motivated by a desire to improve one's chance (or one's children's chance) of success in the marriage market. Yet the fraction of young men who will not get married in the aggregate is determined by the sex ratio, and not by the economy-wide work effort, risk-taking, or GDP growth rate. In this sense, the extra work effort and risk-taking are futile; households collectively would have been willing to give up this part of income growth in exchange for no sex ratio imbalance.

Thus, from 1980 to 2011, China was experiencing a relatively low wage, a large work force with a favorable dependency ratio, and an increasingly unbalanced sex ratio in the pre-marital cohort. But starting in 2011, China's age cohort of 15–60 started to shrink in absolute size. Policy changes to postpone the official retirement age or to encourage more female labor force participation will at best moderate the resulting decline in the work force. Because the female labor force participation was very high under the central planning regime before the 1980s, higher than most non-Communist countries in the world, such as the United States, Japan, Germany, India, and Indonesia, the participation rate of women in the labor force has in fact come down over time. The recent relaxation of the family planning policy in November 2015 from the limit of one child per couple to two children per couple, while motivated to improve the demographic pattern for the economy, will make the dependency ratio worse for the next decade-and-a-half rather than better by adding to the number of children, without altering the size of the work force. After all, no couple can produce a 16-year old right away (Wei 2015). The sex ratio at birth has started to become less unbalanced in 2009, and the contribution to growth from an unbalanced sex ratio will become weaker over time.[1]

3. Evolution of the Aggregate Productivity

To see how the growth of physical capital, human capital (work force adjusted for average years of schooling), and total factor productivity each contributes to China's GDP growth, we perform a simple decomposition based on an aggregate production function

[1] Beside a moderation of growth since 2012, China has to deal with challenges associated with income inequality, regional disparity, environmental degradation, and corruption. For perspectives on these challenges, see Fan, Kanbur, Wei, and Zhang, 2014.

approach.[2] Figure 1 summarizes the result. A few features are worth noting. First, investment in physical capital has always been important for China's growth, accounting for 67.9 percent on average throughout this period. The relative share of contribution from physical investment increased to 107 percent after 2009, which resulted from the government stimulus package in response to the global financial crisis. Second, the contribution from the growth of human capital has been positive, at 12.5 percent during 1999-2008 and 16 percent during 2009-2015. Because of the outsized role of physical investment in the Chinese economy, the contribution of human capital is smaller than what one typically finds from growth decomposition for an OECD economy. Third, the growth of total factor productivity was a major contributor to GDP growth before 2008, often accounting for 20 percent or more to the total growth. (An exception was the period of 1989-1991, a time of domestic political turbulence and international sanctions).

Strikingly, the contributions from the growth of total factor productivity have turned persistently negative since 2009.[3] Upon reflection, this is perhaps not overly surprising. The Chinese government's response to the global financial crisis that started in 2008 was to encourage physical investment through an aggressive fiscal (and bank lending) program, but there were no ambitious structural reforms pursued during this period that could have raised aggregate efficiency, and yet GDP growth started to moderate after 2012—and this combination is a recipe for negative growth in total factor productivity.

The Chinese economy is at a crossroads. Structural factors in the form of less favorable demographics and a higher cost of labor imply a lower potential growth rate. To achieve robust future growth, raising the growth of total factor productivity is a must.

One way to raise future productivity growth is to pursue more structural reforms. These include removing barriers to labor mobility from rural to urban areas (the *hukou* system) and leveling uneven access to bank loans by firms of different ownership. Another way to raise productivity growth is via innovation. Innovation can take the form of creating new products, new ways of using existing products, new designs, new processes for producing existing products that are more efficient and cost-effective, new ways of organizing business, and new ways of branding and marketing the products or services.

Can China transition from a world assembly line to an innovation powerhouse? It's easy to list reasons to be skeptical. There is no shortage of news stories of intellectual property rights violations by Chinese companies[4]. There is criticism that the Chinese school system puts too much weight on rote learning and not enough on creative and critical thinking. On the other

[2] The computation method and data sources are explained in online Appendix A, available with this paper at http://e-jep.org.

[3] The baseline calculation assumes a capital income share of 0.50. We vary the share from 0.4 and 0.55 and find that the broad pattern of the evolution of total factor productivity stays the same. Our finding is broadly consistent with Wu (2014). For example, he reported negative total factor productivity from 2007 to 2012, while our estimate indicates such a decline from 2009 to 2014. One difference between Wu and our growth decomposition is that he obtains a larger contribution from human capital, which may be related to the way the schooling adjustment is made.

[4] Fang, Lerner, and Wu (2016) provide evidence that regional variations in the strength of intellectual property rights protection in China are correlated with propensity to innovate for privatized formally state-owned firms.

hand, more optimistic examples are available, too. Tencent, the company that provides the popular communication tool, WeChat, which combines group chat, voice calls, video sharing, and financial exchanges, is generally regarded as among the most innovative internet companies in the world. Huawei, the telecom equipment producer, is said to take out more patents a year than either Apple or Cisco. The world's first quantum satellite was launched by China in August 2016. To address whether such examples of innovation are exceptions or the norm, we offer a systematic look at the data in the next section.

It is hard to quantify with precision the relative contributions to total factor productivity growth from different sources. From the *China Statistical Yearbook on Science and Technology*, we compute and compare investment made by firms in the survey in (a) importing and digesting foreign technologies, (b) buying and digesting technologies from other domestic firms, and (c) developing their own in-house technological improvement. In 2000, the survey firms collectively spent nearly 20 percent of their technology improvement budget on importing and digesting foreign technology, about 2 percent on buying technologies from other domestic sources, and 78 percent on developing their own in-house technological improvement. Over time, the share of the first item declines, whereas the last two items expand. By 2014, the survey firms collectively spent 11 percent of their technological improvement budget on importing and digesting international technologies, about 5 percent on buying technologies from domestic sources, and the remaining 84 percent on developing their own in-house technological advancement, both reflecting a significant increase over the shares in 2000 (see Appendix Figure A1). These numbers indicate in an indirect way the improvement in the domestic innovation capacity in China's manufacturing sector.

4. **Research and Development: Investment and People**

Innovative leaders at both the corporate and national levels tend to invest heavily in research and development. The United States, Japan and Germany, the largest three rich economies, invested more than 2.7 percent of their GDP in research and development in 2014, which is almost 50 percent more than an average OECD country (about 1.9 percent in 2014), and about three times as much as most developing countries. If China makes the transition to a more innovative economy, it needs to make a commitment to research and investment spending as well.

In 1991, when systematic data on this subject started to be collected, China invested 0.7 percent of GDP in research and development. This was much lower than technological leaders like the United States, Japan, and Germany, but not out of line with big developing economies such as India, Brazil or South Africa. Indeed, because China's competitiveness at this time was based on exploiting its vast cheap labor and making use of technologies developed elsewhere, domestic research and development and innovation were not an imperative at this time.

A comparison of research and development spending between China and other economies is provided in Figure 2. For all countries in the world other than China, we plot research and development expenditure as a share of GDP in the latest possible year (which is

2014 for most countries). Clearly, higher-income countries tend to have a higher ratio of research and development spending to GDP. For China, we plot the same ratio using corresponding data for China from 1995 to 2014. By 2010, China has reached the median value of research and development as a share of GDP. By 2012, its spending had caught up with the OECD average (at 1.88 percent of GDP in that year) even though China's income level was still less than one fifth of the OECD average. By 2014, China's research and development spending had reached 2.05 percent of GDP. From an aggregate spending viewpoint, China is an overachiever.

Another indicator of innovation effort is the share of researchers in the population. In 1996, China had 443 researchers per million people. In comparison, the shares for the United States, Japan, and Korea were 3,122, 4,947, and 2,211 per million, respectively. The Chinese ratio in 1996 was comparable to Brazil (420 per million in 2000) and better than India (153 per million in 1996), though much lower than Russia (3,796 per million in 1996). By 2014, the share in China had grown to 1,113 researchers per million population.[5] Because China's research and development expenditure has grown faster than the number of researchers, research and development expenditure *per researcher* has grown over time as well.

5. The Pace of Innovation as Measured by Growth in Patents

Not all dimensions of innovation are equally well measured. The output of innovation can take the form of patents, commercial secrets, improvement in business processes or business models and others. Innovation can also take place in areas outside the commercial space, such as culture. Since innovation in the form of patents is relatively well measured, we will pay special attention to patents by firms.. Our conjecture is that innovation across all dimensions is positively correlated.[6]

The number of Chinese patents has exploded: Table 2 presents some summary statistics. The number of patent applications filed in China's State Intellectual Property Office (SIPO) rocketed from 83,045 in 1995 to more than 2.3 million in 2014, at an annual growth rate of 19 percent (column 1). In 2011, China overtook the United States as the country with the most patent filings in the world that year (based on data from WIPO).

What explains the explosion of Chinese patents? Could it be easy approval or low-quality of patents in China? Some straightforward comparisons across countries suggest that neither is a likely explanation.

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[5] For more cross-country comparisons, see Appendix Figure A2, available with this paper at http://e-jep.org.

[6] A simple regression of firm level total factor productivity, estimated using the Olley-Pakes method based on data from the Annual Survey of Manufacturing Firms, on the cumulative number of patents yields a positive slope coefficient. In other words, firm-level total factor productivity and the stock of patents are positively correlated. Fang, He, and Li (2016) also show a positive association between firm level total factor productivity and patent count. They interpret it as patent innovation raising productivity; such an interpretation would need an instrumental variable approach to back it up.

One simple metric for judging ease of patent approval is the ratio of the number of patents granted in year t to the number of patent applications in year t-1, which we will call the patent approval rate. Based on data from the World Intellectual Property Organization, the patent approval rate in China in recent years is 30-40 percent, which is essentially in the middle of the approval rates across countries. For example, the Chinese approval rate is higher than those in India and Brazil, which are close to 20 percent, but lower than those in the United States and Korea, which are in the range of 50-60 percent. Therefore, the Chinese patent approval ratio does not seem to be unusually high.

Among the three types of patents (invention, utility model, and design), the fraction of approved invention patents, arguably the most technically intensive category, rose from 8 percent in 1995 to 18 percent in 2014 (Column 2 of Table 2). In 2005, patents granted to foreign applicants accounted for more than 20 percent of China's total approved patents, but dropped to 7 percent in 2014, suggesting an increasing role of indigenous innovations in the Chinese economy since 2005. As Table 2 shows, both total Chinese patents filing and approvals show a rapid growth.[7]

One way to consider the quality of Chinese patents is to examine patents applied by and granted to Chinese firms in other countries. As noted earlier, the rate of patents approved by China's patent office grew at an annual rate of 19 percent from 1995 to 2014. During that period, the number of patents granted to Chinese applicants by patent offices in developed countries was rising even faster at 28 percent per year (see last column in Table 2).

Of particular interest is a comparison of the number of patents granted by the US Patent and Trademark Office (USPTO) to Chinese firms with those to firms from other countries. As shown in Table 3, the number of patents granted by the USPTO to Chinese corporate applicants rose from 62 in 1995 to 7,236 in 2014. The annual growth rate was 21 percent in the first half of the period (1995-2005) but accelerated to 38 percent a year during the latter half of the period (2005-2014). Of the comparison countries—Brazil, Russia, India, South Africa, German, Japan, and Korea—only India had a similar rate of growth in corporate patents in the United States.

Two natural adjustments are to consider a country's population size and income level. To this end, we run cross-country regressions with log number of patents granted to applicants from various comparison countries by the US Patent and Trademark Office as the dependent variable. As explanatory variables, we use the log of population, squared log of population, and country x year fixed effects. Figure 3 plots the estimated coefficients for the interaction term between county and year fixed effects for selected counties. These coefficients can be interpreted as how a given country does relative to the average international experience based on its population size. China shows steady gains in patents even with these adjustments. Of the comparison countries,

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[7] The online appendix available with this paper at http://e-jep.org includes more detail on patent data. For example, Appendix tables A2 and A3 provide more detail on Chinese patent filings and approvals, while Appendix Figure 3 provides more details on cross-country comparisons of patent approval rates.

India also shows gains over time after these adjustments, but Japan, Germany, the Republic of Korea, Brazil, Russia, and South Africa do not. Overall, Chinese firms collectively do better in their patent count than what the country's population size and income level would have suggested.[8]

One can also look at foreign citations of Chinese patents (granted by China's State Intellectual Property Office). The count of foreign citations of Chinese invention patents grew at the rate of 33 percent a year during 1995-2005, but accelerated to 51 percent a year from 2005 to 2014. The growth of citations of Chinese utility model patents is similar, at 36 percent per year during 1995-2014. After adjusting for population size and income, Chinese firms perform well.[9] This pattern is consistent with international recognition of rising scientific and innovative ideas out of China.

Overall, not only has the number of Chinese patents exploded, but a variety of comparisons suggest that Chinese patent quality also exhibits a real and robust improvement over time that is quite favorable relative to international experience. There is no reason to be pessimistic about the intrinsic ability for Chinese firms to innovate.

6. Patterns of Innovation Growth

By looking at patterns of patents across different categories of industries, we can gain insight into some of the factors as potential drivers of innovation, including the rise in relevant market size, industrial competition, market size, and change in relative prices (such as rising wages). We merge the Chinese patent database with the Annual Survey of Industrial Enterprises in China (ASIEC). The ASIEC database covers all the state-owned enterprises and private firms with sales exceeding 5 million yuan from 1998 to 2009, including ownership information.[10] The patent database contains all patents granted by China's State Intellectual Property Office between 1985 and 2012. One pattern that emerges is that state-owned enterprises in general perform worse than private firms in generating patents. During the period 1998–2009, the number of patents granted to private firms in China grew by 35 percent per year, overtaking the number of patents given to state-owned and foreign firms by a comfortable margin. The drop in the share of patents by state-owned enterprises is partly due to the shrinkage of that sector, as described

[8]Details of the regressions are available in an online appendix available with this paper at http://e-jep.org. See Appendix Table A5.

[9] We perform cross country regressions similar to those described in Figure 3 with the forward citation of Chinese firms' patents by all patent applicants in the United States as the dependent variable. The appendix table A5 provides more detail on the extent of forward citation across countries regression analysis, and appendix Figure A4 shows the coefficients on the interaction term between country and year fixed effects against log income. Overall, relative to a country's population size and income level, the Chinese firms do well in terms of forward citations of their patents. See also Xie and Zhang (2015) for an analysis of the growth of patents in China.

[10] While ASIEC data for 2010–2014 seem to be available on the gray market, the quality appears suspect. To be conservative, we do not use these data in this paper.

earlier. In 1998, state-owned enterprises accounted for 30 percent of total firms in the ASIEC database, while they dropped to 2 percent by 2009. Clearly, private firms have become the engine of innovation in China.

Market size has been regarded as a key driver of innovation in the literature (Acemoglu and Linn 2004). In other words, firms aiming at larger global markets should be more innovative. In past decades, the Chinese economy has become increasingly integrated with the world economy, in particular since China joined the World Trade Organization in 2001. In this data, exporting firms in China are indeed more innovative than non-exporting firms.

Since 2003, real wages in China have grown by more than 10 percent a year. Some reckon that China has passed the so-called "Lewis turning point," which means that an era of ultra-low-wage production is over (for example, Zhang et al. 2011). While patents are rising for both capital- and labor-intensive firms, the fraction of patents granted to labor-intensive firms increased from 55 percent in 1998 to 66 percent in 2009. Rising labor costs may have induced labor-intensive sectors to come up with more innovations to substitute for labor.[11]

We can connect the discussions on total factor productivity and on innovation. We separate all firms in the ASIEC sample into those with no patents during 1998-2007, those with a cumulative patent count of 1-4 patents during the same period, and those with a cumulative count of more than 4 patents. We compute the growth of total factor productivity for each individual firm. We find that firm-level productivity tends to grow faster in the group that engages in more innovation. This suggests that to reverse China's negative levels of total factor productivity, it would be helpful for China to facilitate conditions that expand both the number of firms that engage in innovative activities and the intensity of innovation per innovating firm.

7. Misallocation of Innovation Resources

The innovation gap between China and leading advanced economies such as the United States, Japan, and even Korea is still wide. On the list of 2015 Thomson Reuters' Top 100 Global Innovators, Japanese and US firms lead the way, while no single Chinese firm makes the list. More systematic data confirms the continued gap in innovation (Shen, Wang, and Whalley 2015). The numbers of US patents received by either Japanese, German, or Korean firms are still more than twice as many as those obtained by Chinese firms in spite of their smaller population size (as shown earlier in Table 3). Part of the gap reflects different stages of development: as we have shown, both investment in R&D and innovation measured by patent count are strongly

[11] The descriptions in these paragraphs are based on bivariate correlations, and as such, are of course only suggestive. In order to evaluate the relative importance of these factors' contributions to firm innovations in a more rigorous manner, we run multivariate regressions using a hybrid binomial estimation method proposed by Allison (2005). The details are available in the online Appendix B available with this paper at http://e-jep.org (see Appendix Tables A7-A11). Overall, the findings confirm the importance of rising labor cost.

positively related to GDP per capita. However, another contributor to the gap could be resource misallocation in the innovation space. We turn to this topic next.

Following China's reforms in the late 1990s, the share of state-owned enterprises in total firms dropped significantly from 24 percent 1995 to 3 percent in 2014, as discussed earlier. However, most of the surviving state-owned enterprises are relatively big, and are in upstream industries or strategically important sectors (Hsieh and Song 2015). They are typically subject to less competition than private enterprises. Thus, China's state-owned firms both absorb non-trivial resources, including government subsidies, and still command non-trivial political weights. Part of China's move to becoming an innovative economy must be to improve the efficiency of resource allocation between state-owned and private firms. China's state-owned firms continue to receive considerable financial support from the government, including access to low-cost bank loans and research and development subsidies. In the aftermath of both the 1997 Asian financial crisis and the 2008 global financial crisis, the Chinese government launched stimulus packages which often involved credit expansion and which disproportionately went to state-owned enterprises. The more favorable policies and injection of massive stimulus funds have reduced the returns to capital of state-owned enterprises since 2008 (Bai and Zhang 2014), caused a decline in their total factor productivity (Wu 2013), and provided a lifeline for inefficient zombie firms (Tan et al. 2016). The returns to capital of state-owned enterprises are much lower than their private counterparts (Hsieh and Song 2015). Moreover, state-owned enterprises lagged behind private firms in total factor productivity (Brandt 2015). These patterns suggest a misallocation of government support between state-owned and private enterprises. Government subsidies for research and development can promote firm innovations in China (as reviewed in Boeing 2016 and confirmed by our own firm-level regressions). Government subsides can be defended on the ground that research and development by firms generate positive externalities. Indeed, most advanced countries subsidize research and development as well. The question is not whether subsidies can be justified at all, but rather whether China's allocation of such subsidies is consistent with economic efficiency.

Based on simple averages, it would appear that a greater fraction of state-controlled firms are innovative (that is, they have patents) than domestic private sector firms. Indeed, some state-controlled firms receive many patents in a year. But the simple averages are misleading both because state-controlled firms are much larger on average (and larger firms tend to invest more in research and development), and because they tend to receive more subsidies from various levels of the government. Subsidies from local governments to local government-controlled firms are especially noteworthy.

We examine firm-level data for evidence of effectiveness of research and development spending in generating innovations. Based on firms in the ASIEC sample during 2005-2007, for every 10 million yuan of firm-level investment in research and development, domestic private-sector firms and foreign-invested firms generate 6.5 and 7.6 patents, respectively. In comparison, the same investment by state-owned firms yields a more meager 2.2 patents. We may obtain a more informative picture by sorting firms by size and ownership. In Figure 4, on the horizontal axis, all Chinese firms are sorted into ten size deciles based on the sum of the sales during the period, with the first decile being the smallest and the 10^{th} being the largest. Within each size decile, firms are then sorted by ownership. "State" refers to all firms in which the state (either the central or the local governments) have controlling shares (50 percent or more); "foreign" refers to all firms in which foreign entities, including investors from Taiwan, Hong Kong, or Macao, have a 10 percent share or more but the state has no more than 50 percent of the shares. All other firms are in the "private" category.

Table 4 presents statistics on domestically granted patents by firm ownership and size during 2005-2007 when all relevant data are available. In most of the size categories, domestic private sector firms and foreign invested firms invest more in research and development and generate more patents than their state-owned counterparts.

Inspecting Figure 4 and Table 4, several patterns are especially noteworthy. First, the returns to research and development spending—as measured by the number of patents per million yuan of research and development spending on the vertical axis—tend to decline with firm size. Because large firms tend to spend more on research and development, this pattern is consistent with the idea that diminishing returns apply to investment in innovation. Second, across most size deciles, we see that foreign-invested firms and domestic private sector firms tend to have higher returns to investment in research and development. Third, we do not observe a connection between firm subsidies (relative to sales) and effectiveness at converting research and spending into innovative outcome as measured by patents. Instead, we see that state controlled firms tend to have much higher subsidies (relative to sales) than either domestic private firms or foreign invested firms. Interestingly, because small and medium state owned firms are mostly owned by local governments, they receive more subsidies from the local governments than large state owned firms.

Konig et al. (2016) argue that, in theory, the most productive firms should pursue innovation and less productive firms should just imitate. Against this theoretical benchmark and also compared to the data patterns in Taiwan, they find that less productive firms in China engage in too much research and development spending—and the more productive firms may not do enough). Based on their calibrations, if the R&D misallocation can be reduced (so that the association between productivity and R&D spending resembles that in Taiwan), the aggregate productivity growth in Chinese manufacturing during 2001-2007 could have grown by about one-third to one-half.

In sum, there is prima facie evidence that the pattern of subsidies across China's firms represents resource misallocation. China's economy-wide innovative outcomes would have been higher if the subsidies were more evenly spread across firm ownership.[12] Providing subsidies

12 The appendix available online with this paper at http://e-jep.org offers some exploratory regressions that tend to confirm the intuition in the text. In particular, we regress patent count on firm R&D expenditure by controlling for firm sales, firm fixed effects, and year fixed effects. In order to evaluate whether private firms and state-owned enterprises have different elasticity regarding R&D expenditure, we interact firm ownership with R&D expenditure in the regressions. The interaction term between the state-owned enterprise dummy and R&D variable is statistically negative, indicating that the elasticity of patents granted with respect to R&D expenditures is significantly higher for private firms than for SOEs. This finding is consistent with the view that state-owned enterprises have not spent R&D resources as efficiently as private firms.

only in cases where the social returns exceed private returns (such as certain innovative activities) without regard to firm ownership would improve efficiency.

8. Conclusions

China's past success in economic growth means that its real manufacturing wage has increased by about 14-fold from 1980 to 2015. In addition, China's shrinking work force since 2011 has added to the wage pressure. By necessity, China has to move to a growth model that is based more on innovation and productivity increase than in the past.

Can China rise to the challenge? One sometimes hears an argument for the "middle-income trap hypothesis," which claims that only in exceptional cases can a middle-income country ever manage to become an innovative high income economy. Indeed, the challenges facing China have often been expressed in the context of a possible middle income trap by both the government of the country and some scholars (for example, OECD 2013; Ma 2016). Han and Wei (2015) do not find support for an unconditional notion of the middle-income trap hypothesis, using both a transition matrix analysis and a non-parametric analysis (by regression trees). Nonetheless, they identify certain conditions under which growth in a middle-income country could stagnate or even regress.

We have argued that Chinese firms have demonstrated a capacity to become more innovative in response to wage pressure and global opportunities. The data on Chinese patents, both from a quantity and a quality perspective, appear encouraging enough that there is no reason to be overly pessimistic about China's prospects for a successful transition to a more innovation-based growth model.

If China finds effective ways to embrace a shift to a more innovative economy, it can realize its dream faster of moving into the high-income club. The government subsidies tend to favor state-owned firms, and yet both domestic private sector firms and foreign invested firms are more effective in converting investment in R&D to innovation outcomes as measured by patents. Leveling the playing field for firms of all ownership type, limiting the government's discretion in subsidies for research and development, and assuring that private sector firms have a fair chance at receiving those subsidies would reduce resource misallocation and improve efficiency. This will complement the reforms in stronger protection of intellectual property rights and education reforms that place more emphasis on developing critical and creative thinking.

References

Acemoglu, Daron, and Joshua Linn, 2004. “Market Size in Innovation: Theory and Evidence from the Pharmaceutical Industry,” *Quarterly Journal of Economics*, 119 (3): 1049–1090.

Allison, Paul D., 2005. *Fixed Effects Regression Methods for Longitudinal Data Using SAS*. Cary, North Carolina: SAS Institute.

Autor, David H., Frank Levy, and Richard J. Murnane, 2003. “The Skill Content of Recent Technological Change: An Empirical Exploration,” *Quarterly Journal of Economics*, 118 (4): 1279–1333.

Bai, Chong-en, and Qiong Zhang, 2014. “Returns to Capital and Their Determinants in China,” (in Chinese language), *World Economy*, 10: 2–30.

Boeing, Philipp, 2016. “The Allocation and Effectiveness of China’s R&D Subsidies: Evidence from Listed Firms.” *Research Policy* 45(9): 1774–89.

Brandt, Loren, 2015. “Policy Perspectives from the Bottom Up: What Do Firm Level Data Tell Us China Needs to Do?,” Paper presented at the Asia Economic Policy Conference on Policy Challenges in a Diverging Global Economy, Federal Reserve Bank of San Francisco, 19–20 November.

Brandt, Loren, Trevor Tombe, and Xiaodong Zhu. 2013. “Factor Market Distortions across Time, Space and Sectors in China,” *Review of Economic Dynamics*, 16 (1): 39–58.

Cai, Fang, and Yang Du, 2011. “Wage Increases, Wage Convergence, and the Lewis Turning Point in China,” *China Economic Review*, 22 (4): 601–610.

Cai, Fang, and Meiyan Wang, 2008. “A Counterfactual Analysis on Unlimited Surplus Labor in Rural China,” *China & World Economy*, 16 (1): 51–65.

Chang, Simon, and Xiaobo Zhang, 2015. “Mating Competition and Entrepreneurship,” *Journal of Economic Behavior & Organization*, 116 (C): 292–309.

China National Bureau of Statistics (CNBS), 2012. *China Statistical Yearbook*. Beijing: China Statistical Press.

Dang, Jianwei, and Kazuyuki Motohashi, 2015. “Patent Statistics: A Good Indicator for Innovation in China? Patent Subsidy Program Impacts on Patent Quality,” *China Economic Review,* 35 (C): 137–155.

Jing Fang, Hui He, and Nan Li, 2016, “China’s Rising IQ (Innovation Quotient) and Growth: Firm-level Evidence,” unpublished IMF working paper.

Fang, Lily, Josh Lerner, and Chaopeng Wu, 2016, “Intellectual Property Rights Protection, Ownership, and Innovation: Evidence from China,” unpublished working paper, INSEAD, Harvard University, and Xiamen University.

Feng, Shiliang, 2014. “Factor Allocation and Economic Growth in China: Analysis across Regions and Sectors from 1978 to 2012.” Dissertation, Peking University. In Chinese.

Fan, Shenggen, Xiaobo Zhang, and Sherman Robinson, 2003. “Structural Change and Economic Growth in China,” *Review of Development Economics*, 7 (3): 360–377.

Fan, Shenggen, Ravi Kanbur, Shang-Jin Wei, and Xiaobo Zhang, 2014. *The Oxford Companion to the Economics of China*. Oxford: Oxford University Press.

Feenstra, Robert, and Shang-Jin Wei, 2010, *China’s Growing Role in World Trade*. Chicago: University of Chicago Press.

Golley, Jane, and Xin Meng, 2011. “Has China Run Out of Surplus Labour?” *China Economic Review*, 22 (4): 555–572.

Han, Xuehui, and Shang-Jin Wei, 2015, “Re-examining the Middle Income Trap Hypothesis (MITH): What to Reject and What to Revive?” CEPR Discussion Paper 10989.

Hsieh, Chang-Tai, and Peter J. Klenow, 2009. “Misallocation and Manufacturing TFP in China and India,” *Quarterly Journal of Economics*, 124 (4): 1403–1448.

Hsieh, Chang-Tai, and Zheng (Michael) Song, 2015 “Grasp the Large, Let Go of the Small: The Transformation of the State Sector in China,” *Brookings Papers on Economic Activity*, 50 (1): 295–366.

Knight John, Quheng Deng, and Shi Li, 2011. “The Puzzle of Migrant Labour Shortage and Rural Labour Surplus in China,” *China Economic Review*, 22 (4): 585–600.

König, Michael, Zheng M. Song, Kjetil Storesletten, Fabrizio Zilibotti, 2016, “From imitation to innovation: Where is all that Chinese R&D going?” (paper not yet completed; the authors provide an abstract).

Li, Bin, 2011. "Comparative Analysis of Estimates on Capital Stock of China." *Journal of Quantitative & Technical Economics* (12): 21-36. In Chinese.

Lin, Justin, 1992. “Rural Reforms and Agricultural Growth in China,” *American Economic Review*, 82 (1): 34–51.

Ma, Damien, 2016, “Can China Avoid the Middle Income Trap?” *Foreign Policy*, March.

OECD, 2013, “The People’s Republic of China - Avoiding the Middle-Income Trap: Policies for Sustained and Inclusive Growth,” September. Paris: OECD.

Qian, Yingyi, and Barry Weingast, 1997, “Federalism as a Commitment to Preserving Market Incentives,” *Journal of Economic Perspectives*, 11(4): 83-92.

Qu, Yue, Fang Cai, and Xiaobo Zhang, 2013. “Has the Flying Geese Paradigm Occurred in China?” *China Economist*, 8 (6): 18–31.

Shen, Keting, Jing Wang, and John Whalley, 2015. "Measuring Changes in the Bilateral Technology Gaps between China, India and the U.S. 1979-2008." National Bureau of Economic Research Working Paper No. 21657.

Tan, Yuyan, Yiping Huang, and Wing Thye Woo, 2016. "Zombie Firms and the Crowding-Out of Private Investment in China," *Asian Economic Papers,*15(3).

Wang, Xiaobing, Jikun Huang, Linxiu Zhang, and Scott Rozelle, 2011. "The Rise of Migration and the Fall of Self-employment in Rural China's Labor Market," *China Economic Review*, 22 (4): 573–584.

Wei, Shang-Jin, 2015, "Freer Choice, Lower Growth, and Higher Welfare: Recent Changes in China's Population Control Policy and the Impact on Its Economy." Keynote (Dinner) Address at the Asia Economic Policy Conference, *Policy Challenges in a Diverging Global Economy,* organized by the Federal Reserve Bank of San Francisco on November 19–20.

Wei, Shang-Jin, and Xiaobo Zhang, 2011a. "The Competitive Saving Motive: Evidence from Rising Sex Ratios and Savings in China," *Journal of Political Economy*, 119 (3): 511–564.

Wei, Shang-Jin, and Xiaobo Zhang, 2011b. "Sex Ratios, Entrepreneurship and Economic Growth in the People's Republic of China," NBER Working Paper No. 16800, National Bureau of Economic Research, Cambridge, Massachusetts.

Wei, Shang-Jin, Xiaobo Zhang, and Yin Liu, 2016. Home Ownership as Status Competition: Some Theory and Evidence," *Journal of Development Economics*, forthcoming.

World Intellectual Property Organization (WIPO), 2012. *World Intellectual Property Indicators*. Geneva: WIPO.

Wu, Harry X. 2013. "Measuring and Interpreting Total Factor Productivity in Chinese Industry," *Comparative Studies*, 69. Available: http://magazine.caixin.com/2013/cs_69/.

Wu, Harry X. 2014. "China's Growth and Productivity Performance Debate Revisited: Accounting for China's Sources of Growth with a New Data Set." Economics Program Working Paper Series No. #04-01, Conference Board. Available from https://www.conference-board.org/pdf_free/workingpapers/EPWP1401.pdf.

Xie, Zhuan, and Xiaobo Zhang, 2015. "The Patterns of Patents in China," *China Economic Journal*, 8 (2): 122–142.

Xu, Chenggang, 2011, "The Fundamental Institutions of China's Reforms and Development," *Journal of Economic Literature*, 49(4): 1076-1151.

Xu, Chenggang, and Xiaobo Zhang, 2009. "The Evolution of Chinese Entrepreneurial Firms: Township-Village Enterprises Revisited," International Food Policy Research Institute Discussion Paper # 0854, Washington, DC.

Zhang, Xiaobo, Jin Yang, and Shenglin Wang, 2011. "China Has Reached the Lewis Turning Point," *China Economic Review*, 22 (4): 542–554.

Zhu, Xiaodong, 2012. “Understanding China’s Growth: Past, Present, and Future,” *Journal of Economic Perspectives*, 26 (4): 103–124.

Table 1—Number of Registered Firms in China (1995-2014)

	Firm count at year end	Private (%)	State-owned Firms (%)	Foreign (%)
1995	4,598,604	71	24	5
2000	5,875,706	76	19	5
2005	7,980,991	85	10	5
2010	11,150,201	90	5	5
2014	18,178,921	94	3	3
Annual growth rate (%)				
1995–2005	6	8	-3	5
2005–2014	10	11	-5	3
1995–2014	8	9	-4	4

Note: Tabulated by authors based on China Firm Registry Database. State-owned firms refer to firms with the state (either central or local governments) owning 50% or more. Foreign firms refer to firms with foreign ownership exceeding 10%. All other firms are in the "private" column.

Table 2—Patent Applications and Patents Granted (1995–2014)

Year	Number of patent applications at SIPO (1)	Number of patents granted by SIPO (2)	Distribution of patents granted by type of patents (3)			Share of patents granted to applicants from outside China (%) (4)	Number of patents granted by foreign patent offices to China based applicants (5)
			Invention (%)	Utility model (%)	Design (%)		
1995	83,045	45,064	8	68	25	8	99
2000	170,682	105,345	12	52	36	10	157
2005	476,264	214,003	25	37	38	20	539
2010	1,222,286	814,825	17	42	41	9	3,434
2014	2,361,243	1,302,687	18	54	28	7	10,282
Annual growth rate in different periods (%)							
1995–2005	19	17	31	10	22	28	18
2005–2014	19	22	18	27	18	9	38
1995–2014	19	19	25	18	20	18	28

Note: Authors' tabulation based on data from China's State Intellectual Property Office's (SIPO's) webpage (http://www.sipo.gov.cn/tjxx/) for columns (1)-(4) and World Intellectual Property Office (WIPO) for Column (5).

Table 3—Number of patents granted by USPTO to international corporate applicants

Year	China	Brazil	India	Russia	South Africa	Germany	Japan	Rep. of Korea
1995	62	63	37	98	123	6,600	21,764	1,161
2000	119	98	131	183	111	10,234	31,296	3,314
2005	402	77	384	148	87	9,011	30,341	4,352
2010	2,657	175	1,098	272	116	12,363	44,814	11,671
2014	7,236	334	2,987	445	152	16,550	53,849	16,469
Annual growth rate in different periods (%)								
1995–2005	21	2	26	4	-3	3	3	14
2005–2014	38	18	26	13	6	7	7	16
1995–2014	28	9	26	8	1	5	5	15

Note: Computed by authors based on data from US PTO.

Table 4—Patents, Research and Development Expenditure, and Subsidies by Firm Type and Size

	Firm type	Size by sales quantile				
		0-20%	20-40%	40-60%	60-80%	80-100%
Number of patents	Private	1107	2630	4003	7585	64586
	Foreign	226	579	876	3031	44178
	State	46	87	177	351	9116
R&D expenditure (million RMBs)	Private	769	1763	3335	7933	143848
	Foreign	122	312	760	2333	86946
	State	41	112	210	595	51172
(Subsidies/sales) x100	Private	0.22	0.25	0.25	0.24	0.31
	Foreign	0.13	0.11	0.11	0.11	0.11
	State	0.84	0.86	0.71	0.74	0.27

Note: 2005-2007 sample; divide into 5 groups by sales; drop observations that invest less than 100 Yuan but have positive patents.

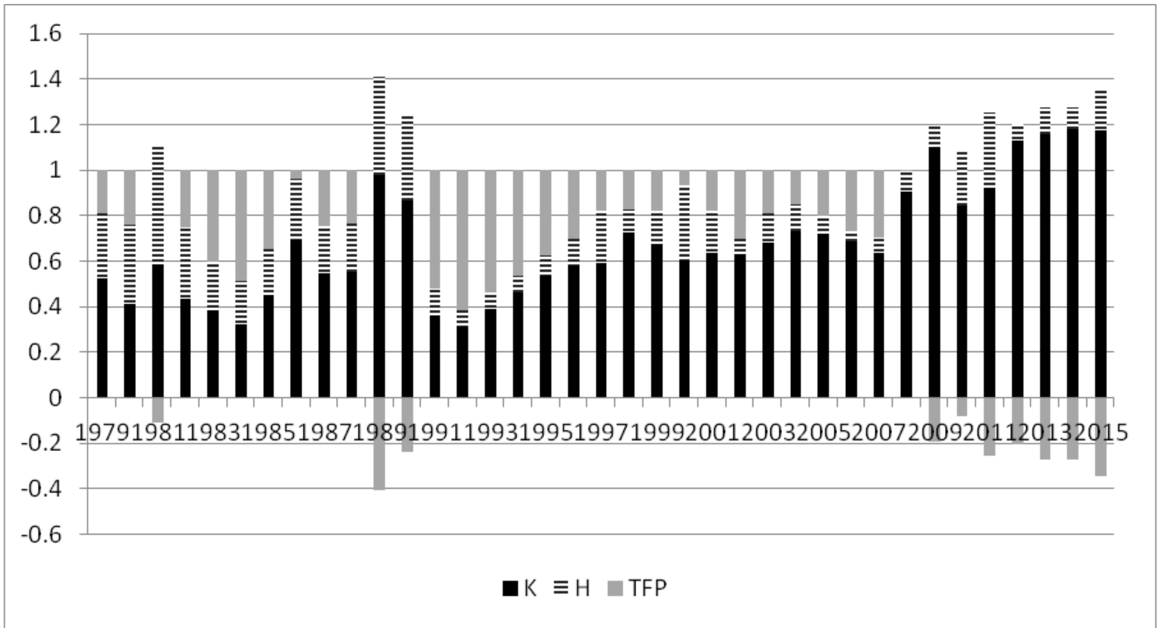

Figure 1: Contributions to GDP Growth of Physical Capital, Human Capital, and Total Factor Productivity, 1979-2015

Note: See Appendix for details of the estimation.

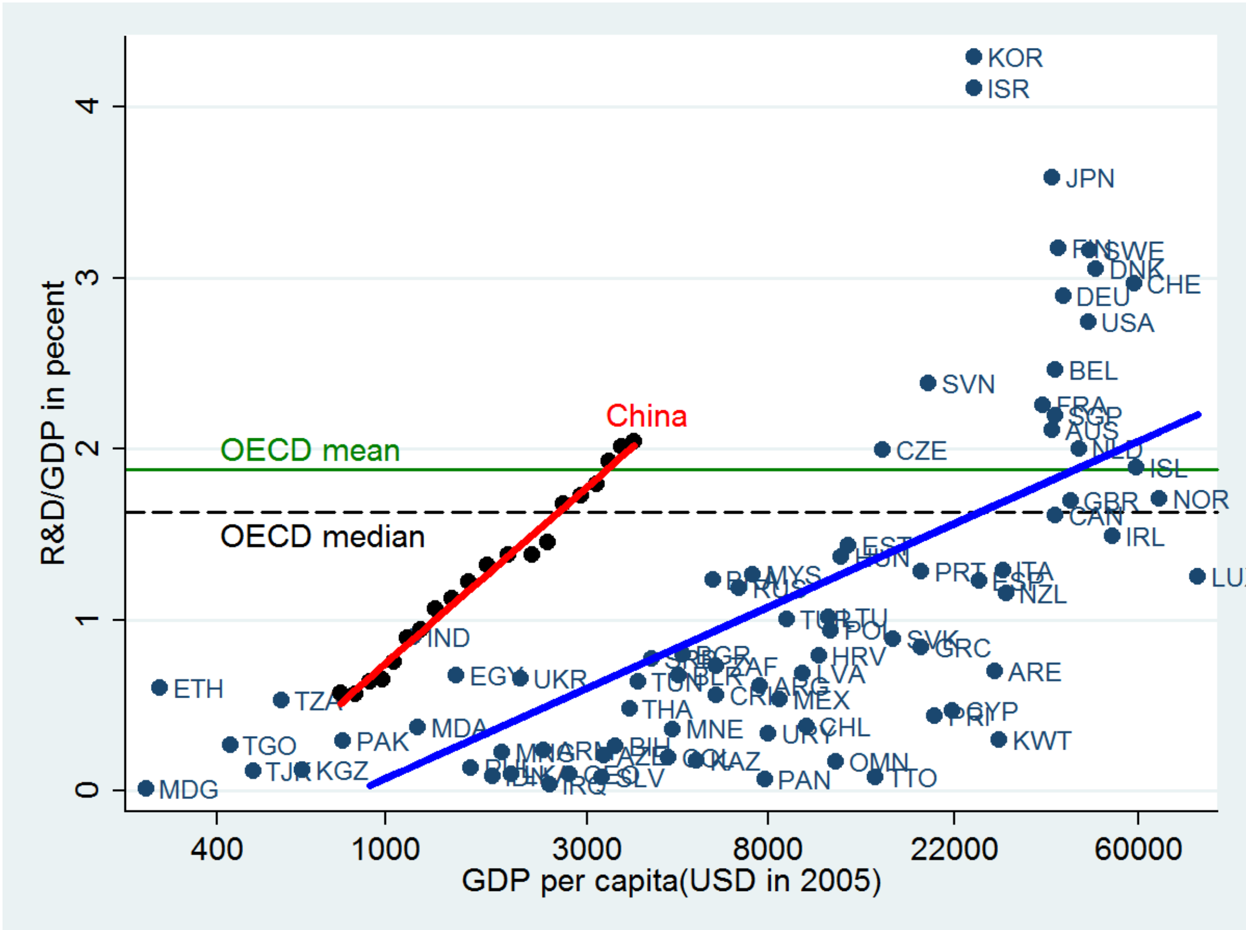

Figure 2—R&D Spending as a Share of GDP: International Comparisons

Note: Data for China are from 1995 to 2014, and data for all other countries are for 2014 or the latest year available.

Source: World Bank, OECD database (https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm)

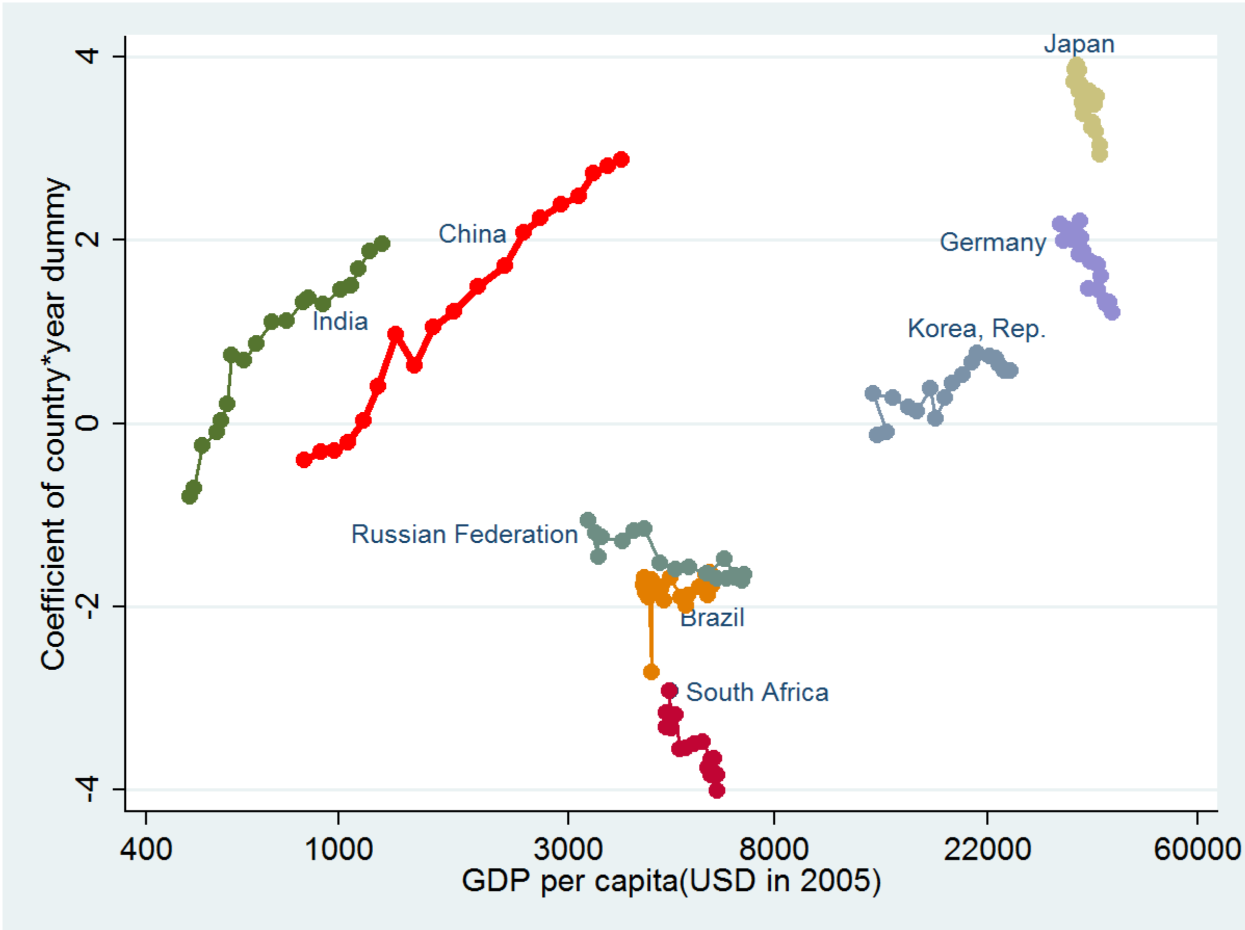

Figure 3—Patents Granted in USPTO to Different Countries

Note: Conditional plot by controlling for population, population squared, and country and year fixed effects, based on data from World Intellectual Property Office (WIPO).

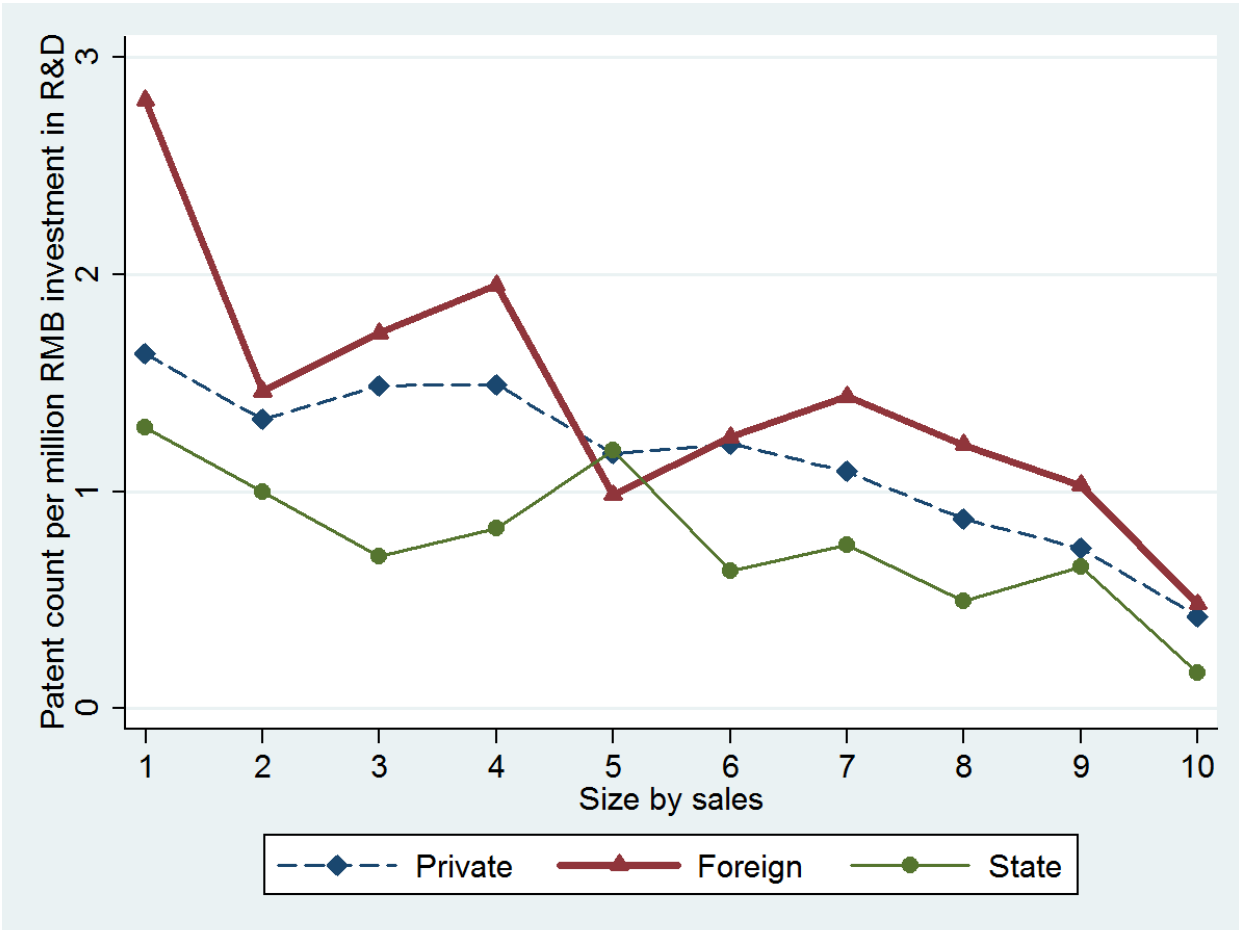

Figure 4—Patent count per million yuan of R&D investment as a function of ownership and size

Notes: 2005-2007 sample; Firms are first sorted by size (sales) deciles, and, within each size decile, are subdivided into three ownership groups. "State" refers to firms for which the state (central or local governments) has 50% share or more. "Foreign" refers to firms for which foreign entities have at least 10% of the share and the state has less than 50% share. "Private" includes all other firms. Firms that report positive patents but no R&D spending (or of less than 100 yuan) are excluded.

Online Appendix A: Decomposition of GDP Growth

To decompose GDP growth and to compute total factor productivity, we need data on physical capital, human capital, and output.

For physical capital, we refer to Li (2011) for a summary and comparison of different estimates in the existing literature. We use the investment data for 1953-2009 from Li (2011) and extend it to 2015 by using data on fixed capital formation from the National Bureau of Statistics, and employ a perpetual inventory method to estimate capital stock. For the discount rate, we use the data from Li (2011) before 1992, and 6% after 1992.[13] For price index, we use the "price index of fixed asset investment" provided by the National Bureau of Statistics, which is also Li's source for data before 1991.

Human capital is the product of the size of the labor force and average years of schooling. The size of labor force is from the National Bureau of Statistics. For average years of schooling, we use the estimates for 1978-2012 from Feng (2014) and extend it to 2015.

We need information on the share of labor income in national income. The share is computed by Li (2011) as 47% between 1993 and 2009. Based on data from National Bureau of Statistics, we compute the share to be about 50% between 2000 and 2015. We assume the share to be 50% in our baseline calculations.

Denoting the growth rates of physical capital, human capital and output by g_K, g_H and g_Y, respectively, the growth of total factor productivity is computed as: TFP=g_Y -0.5*g_K -0.5* g_Y.

Out of concern that the estimated labor share in national income may be biased downward, we also use a share of 55%, 60% and 65% as sensitivity checks. We find that the new shares have only negligible effects on the TFP growth patterns.

We can do straightforward decomposition of GDP growth into contributions from various factors. The contributions from physical and human capital are 0.5*g_K/g_Y, and 0.5*g_H/g_Y, respectively, and that from TFP growth is 1 minus the contributions from the other two. The decomposition results are presented in Figure 1.

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[13] As sensitivity checks, we have also used 5%, 8% and 10%. This makes some difference on the level of TFP but not much on the growth rate, which is the key interest of the paper.

Online Appendix B: Investigating the Underlying Causes of Innovation with Patent Data

Because many firms do not have patents and patent count does not follow a log-normal distribution, we cannot use ordinary least square regressions by taking the log on patent count. A common approach is to use a negative binomial model. However, all the observations with zero patents will be dropped when including firm fixed effects. Here we use a hybrid binomial estimation method proposed by Allison (2005): First, we compute the mean values of all the explanatory variables X. Second, we create a set of new variables by deducting the mean values from the original values of X—that is, X – mean of X. Third, we run a random negative binomial model on patent count using these newly created variables as independent variables. This method is a hybrid of the fixed effect and random effect models, largely overcoming the shortcomings of the conditional estimated fixed effect negative binomial model, which automatically drops observations with zero values for the outcome variable for all the years. The equation can be written as:

$P_{ijt} = F(Sales_{it}, Wage_{jt}, Subsidy_{jt}, Taxrate_{jt}, Interest\ rate_{jt}\ , Tariff_{jt}, Export_{it}, HH_{jt},$ industry or firm fixed effects, and year fixed effects),

where *P* = the number of approved patents for firm *i* in year *t, Sales* = firm *i*'s annual sales in year *t, Wage* = average wage at the city-industry-year-firm ownership level (excluding the firm itself) in the cell where the firm is located, *Subsidy* = the ratio of subsidies received from the government to total sales at the firm level*, Tax rate* = the sum of the income tax payment and value added tax payment relative to total sales at the firm level in year *t*, *Interest rate* = the ratio of total interest paid to the average liability this year and last year at the firm level*, Tariff* = weighted average of trade partners' tariff rates, based on matching product-level tariff data from the COMTRADE database with firm *i*'s SIC-2 code (computed at the industry-year level, which we use mainly to improve the matching rate); *Export* is a dummy variable indicating whether a firm has positive exports in year *t,* and finally *HH* is the Herfindahl-Hirschman (HH) index at the industry-year level. The HH index is calculated via the following steps: (1) for every four-digit industry and year *t*, compute every firm's market share, (2) for every four-digit industry and year *t*, sum the square of every firm's market share. The higher the HH index, the lower the degree of competition.

Many of the regressors are undoubtedly endogenous. In the spirit of an instrumental variable approach, we replace the wage rate, subsidy rate, tax rate, and interest rate from firm-year specific values with the average values of all other firms in the same cell of city-industry-ownership type-year. The idea (or the maintained assumption) is that the average values of all other firms in the same cell more likely reflect local labor market conditions (in the case of wage) or local policy designs (in the case of the other three variables). To do this exercise, we also drop all cells with fewer than five observations. Note that we regard the tariff variable as exogenous since it is the average of trading partners' tariff rates, which are unlikely to be systematically manipulated by individual firms in China.

Table A7 reports the hybrid negative binomial regression estimates. Several findings are apparent. First, firm size, measured by sales, is positively associated with the number of approved patents. Unsurprisingly, larger firms tend to have more patents approved. Second, export firms are more innovative. We refrain from assigning a causal interpretation to these two coefficients – the positive correlations between firm size and innovativeness and between export status and innovativeness could reflect causal effects in either direction (and probably in both directions). We simply treat these regressors as control variables.

Third, lower import tariff is good for firm innovations through the expansion of international markets for Chinese products. Because foreign tariffs are (largely) exogenous, we interpret this coefficient as reflecting a causal effect – expansion of international markets or export opportunities induces firms to do more innovations.

Fourth, in terms of the effects of fiscal subsidies, there is some evidence that invention patents respond positively to subsidies, but utility and design patents do not show statistically significant responses. Since invention patents are often regarded as "more innovative," one cannot rule out the possibility that firms' innovative activities respond to fiscal incentives.

Similarly, a higher tax rate appears to discourage innovation – the coefficients on the tax rate are negative in all four columns, though they are statistically significant for all patents, and invention and utility patents only.

Fifth, a higher cost of capital as measured by a higher implied interest rate also appears to discourage many types of innovative activities – the coefficients on log interest rate are negative and statistically significant for all patents, and utility and design patents.

Finally, there is a robust positive relationship between wage level and firm innovations. If our strategy of using the average wages of all other firms in the same cell to replace an individual firm's own wage succeeds in removing endogeneity, one might interpret the coefficient as saying that firms, on average, rise to the challenge of higher labor costs by engaging in more innovations.

Of course, innovative industries tend to hire more skilled workers than less innovative industries. In general, skilled workers earn more than unskilled workers, and thereby could produce a positive correlation between average wage and firm innovativeness at the industry level. Note that our regressions in Table A7 include separate firm and year fixed effects (and therefore subsuming separate industry fixed effects). So endogeneity has to come at the level of industry-city-ownership-year. Nonetheless, to further remove endogeneity, we replace current average wage by those of others firms in the same cell by its lagged value, and find qualitatively the same results. (The results are in Appendix Table A8.)

As robustness checks, we have implemented other specifications as well, such as fixed effect negative binomial model, random effect negative binomial model, and fixed effect ordinal linear probability model. The coefficients for most variables are qualitatively similar. We use minimum wage at the city-year level to replace the average wage of other firms in the same cell, and again find the same qualitative results (see Appendix Table A9).

The same wage increase means a different magnitude of cost shock to firms in labor-intensive industries and firms in other industries. To explore this feature, we now add an interaction term between the average wage of other firms in the same cell and a dummy indicating that the industry in which the firm operates has a labor intensity (labor cost as a share of total cost) above the median at the beginning of the sample. Appendix Table A10 displays the estimation results. The coefficient for the interaction term is positive and statistically significant among three out of four regressions (for total patents, and invention and design patents). Consistent with the induced innovation theory, rising labor costs have induced labor-intensive firms to become more innovative to survive. The results in Table A10 are again robust to the use of alternative wage variables (either lagged wages or legal minimum wages). To save space, the estimates using lagged wages or minimum wages are not reported here.

Studies like Autor et al. (2003) have shown that computer technology has reduced the demand for jobs involving routine tasks. Following Autor et al. (2003), we create a dummy variable "routine" indicating whether an industry involves more routine tasks (1) or not (0). Facing rising labor cost, we expect to see firms heavily involved in routine tasks, which are often done by low-skilled workers, to innovate more to substitute labor. Similar to Table A7, we use a differences-in-difference approach to examine the impact of rising wages on routine task-intensive industries by including an interaction term between wages and a "routine" dummy. As shown in Panel A of Table A11, the coefficient for the interaction term is statistically significant in all four regressions. In response to rising wages, in industries involving routine tasks, those firms that survive (i.e., continue to produce) tend to become more innovative, possibly by taking advantage of computer technologies.

When facing rising labor costs, there are two possible routes for labor-intensive industries. In industries where innovation is possible, firms have to innovate to survive. In industries in which international experience suggests that innovation is difficult (sunset industries), exit or closure is the likely outcome. In the sunset industries, with the dwindling market share, firms may be reluctant to make R&D investment for fear of failure to recoup the cost.

We define the sunset industries as follows: First, we select top 40 economies according to GDP in 2000 excluding China. Next we further narrow down the list by keeping countries with GDP per capita 1.5 times larger than that of China and lower than 12,000 USD (constant in 2005). The list ends up with Argentina, Brazil, Czech Republic, Mexico, Yemen, Poland, Russia, Turkey, Venezuela, and Zambia. Third, we calculate the annual growth rate of each industry by country and obtain the aggregate growth rate for all countries in the list using GDP as weights. An industry is defined as a sunset industry if its average growth rate during the period 1998–2007 is below the median growth rate among all the industries.

Panel B of Table A11 shows the estimates for the interaction term between wages and "sunset" industry dummy. The coefficient is only statistically negative in the regression on invention patents. Invention patents normally involve more R&D input than utility model and design patents. The results are robust when using lagged values of minimum wages in the interaction term. When market prospects loom large, the surviving firms in the sunset industries are less likely to make large R&D investment, thereby yielding a lower number of invention patents than in other industries. Like other economies which are slightly richer than China, the firms in the sunset industries in China will likely experience slower growth and are eventually replaced by sunrise industries.

Appendix Table A1—Number of Chinese Firms

Year	Firm count at year end	Private (%)	SOE (%)	Foreign (%)
1995	4,598,604	71	24	5
1996	4,997,932	72	23	5
1997	5,293,125	72	22	5
1998	5,526,172	73	21	5
1999	5,712,997	74	21	5
2000	5,875,706	76	19	5
2001	6,032,059	77	18	5
2002	6,356,801	79	16	5
2003	6,831,363	81	14	5
2004	7,400,172	83	12	5
2005	7,980,991	85	10	5
2006	8,572,472	86	9	5
2007	8,962,246	87	8	5
2008	9,405,281	88	7	5
2009	10,130,705	89	6	5
2010	11,150,201	90	5	5
2011	12,352,627	91	5	4
2012	13,433,213	92	4	4
2013	15,184,602	93	3	4
2014	18,178,921	94	3	3
Annual growth rate in different periods (%)				
1995–2005	6	8	-3	5
2005–2014	10	11	-5	3
1995–2014	8	9	-4	4

Note: Tabulated by authors based on China Firm Registry Database.

Appendix Table A2—Number of Chinese patent applications (1995–2014)

Year	Number of patent applications in SIPO of China	Number of patent applications in SIPO of China			Share of patent application in SIPO of China by foreign applicants (%)	Number of applications in foreign patent offices by Chinese applicants
		Invention (%)	Utility model (%)	Design (%)		
1995	83,045	26	53	21	17	205
1996	102,735	28	48	24	20	201
1997	114,208	29	44	27	21	178
1998	121,989	29	42	28	21	259
1999	134,239	27	43	30	18	383
2000	170,682	30	40	29	18	652
2001	203,573	31	39	30	19	846
2002	252,631	32	37	31	19	1,138
2003	308,487	34	35	30	19	1,368
2004	353,807	37	32	31	21	2,365
2005	476,264	36	29	34	20	3,258
2006	573,178	37	28	35	18	5,293
2007	693,917	35	26	39	15	6,041
2008	828,328	35	27	38	13	7,099
2009	976,686	32	32	36	10	9,766
2010	1,222,286	32	34	34	9	11,703
2011	1,633,347	32	36	32	8	14,937
2012	2,050,649	32	36	32	7	19,627
2013	2,377,061	35	37	38	6	22,008
2014	2,361,243	39	37	24	6	26,356
Annual growth rate in total number of patents in different periods (%)						
1995–2005	19	23	12	25	21	32
2005–2014	19	21	23	15	5	26
1995–2014	19	22	17	20	13	29

Note: Tabulated by authors based on aggregate data downloaded from China's State Intellectual Property Office's (SIPO's) webpage (http://www.sipo.gov.cn/tjxx/) and World Intellectual Property Office (WIPO).

Appendix Table A3—Number of patents approved in SIPO and patents granted to Chinese applicants from overseas patent offices (1995–2014)

Year	Number of patents approved in SIPO of China	Number of patents approved in SIPO of China			Share of patents approved in SIPO of China by foreign applicants (%)	Number of patents approved in foreign patent offices by Chinese applicants
		Invention (%)	Utility model (%)	Design (%)		
1995	45,064	8	68	25	8	99
1996	43,780	7	62	31	9	97
1997	50,996	7	54	40	9	91
1998	67,889	7	50	43	10	95
1999	100,156	8	56	36	8	126
2000	105,345	12	52	36	10	157
2001	114,251	14	48	38	13	225
2002	132,399	16	43	40	15	334
2003	182,226	20	38	42	18	362
2004	190,238	26	37	37	20	524
2005	214,003	25	37	38	20	539
2006	268,002	22	40	38	16	847
2007	351,782	19	43	38	14	1,013
2008	411,982	23	43	34	14	1,652
2009	581,992	22	35	43	14	2,234
2010	814,825	17	42	41	9	3,434
2011	960,513	18	42	40	8	4,255
2012	1,255,138	17	46	37	7	6,433
2013	1,313,000	16	53	31	6	8,337
2014	1,302,687	18	54	28	7	10,282
Annual growth rate in total number of patents in different periods (%)						
1995–2005	17	31	10	22	28	18
2005–2014	22	18	27	18	9	38
1995–2014	19	25	18	20	18	28

Note: Tabulated by authors based on aggregate data downloaded from China's State Intellectual Property Office's (SIPO's) webpage (http://www.sipo.gov.cn/tjxx/) and World Intellectual Property Office (WIPO).

Appendix Table A4—Total number of patents granted in the United States by USPTO to (corporate) applicants from BRICS, Germany, Japan, and the Republic of Korea

Year	China	Brazil	India	Russia	South Africa	Germany	Japan	Rep. of Korea
1995	62	63	37	98	123	6,600	21,764	1,161
1996	46	63	35	116	111	6,818	23,053	1,493
1997	62	62	47	111	101	7,008	23,179	1,891
1998	72	74	85	189	115	9,095	30,841	3,259
1999	90	91	112	181	110	9,337	31,104	3,562
2000	119	98	131	183	111	10,234	31,296	3,314
2001	195	110	177	234	120	11,260	33,223	3,538
2002	289	33	249	200	114	11,278	34,859	3,786
2003	297	130	341	202	112	11,444	35,517	3,944
2004	404	106	363	169	100	10,779	35,348	4,428
2005	402	77	384	148	87	9,011	30,341	4,352
2006	661	121	481	172	109	10,005	36,807	5,908
2007	772	90	546	188	82	9,051	33,354	6,295
2008	1,225	101	634	176	91	8,915	33,682	7,549
2009	1,655	103	679	196	93	9,000	35,501	8,762
2010	2,657	175	1,098	272	116	12,363	44,814	11,671
2011	3,174	215	1,234	298	123	11,920	46,139	12,262
2012	4,637	196	1,691	331	142	13,835	50,677	13,233
2013	5,928	254	2,424	417	161	15,498	51,919	14,548
2014	7,236	334	2,987	445	152	16,550	53,849	16,469
Annual growth rate in different periods (%)								
1995–2005	21	2	26	4	-3	3	3	14
2005–2014	38	18	26	13	6	7	7	16
1995–2014	28	9	26	8	1	5	5	15

Note: The figures stand for total number of patents granted to applicants from these countries by the U.S. Patent and Trademark Office (USPTO). Computed by authors based on data from World Intellectual Property Office (WIPO).

Appendix Table A5: Cross country comparison of number of patents, number of citations.

(coefficients on the interaction term between China and years are reported below)

Variables	Number of patents	Number of citations
China dummy* year of 1996	-0.404	
China dummy* year of 1997	-0.311	
China dummy* year of 1998	-0.295	
China dummy* year of 1999	-0.207	0.0607
China dummy* year of 2000	0.0323	0.0652
China dummy* year of 2001	0.404	0.901
China dummy* year of 2002	0.976*	1.508
China dummy* year of 2003	0.634	1.553
China dummy* year of 2004	1.053*	1.917*
China dummy* year of 2005	1.218**	2.193**
China dummy* year of 2006	1.497**	2.333**
China dummy* year of 2007	1.725***	2.981***
China dummy* year of 2008	2.084***	3.536***
China dummy* year of 2009	2.241***	3.327***
China dummy* year of 2010	2.391***	3.506***
China dummy* year of 2011	2.486***	
China dummy* year of 2012	2.727***	
China dummy* year of 2013	2.806***	
China dummy* year of 2014	2.876***	

Note: the second column shows the coefficients of China dummy * year from 1996 to 2014. The dependent variable for second column is number of patents approved in USPTO for each country in each year from WIPO (sample is 1995 to 2014), the independent variables includes country* year fixed effect for Germany, Japan, Korea and BRICS, log population, log population square, year fixed effect, and country fixed effect for other countries. The third column shows the coefficients of China dummy * year from 1999 to 2010. The dependent variable for third column is number of citations received of patents approved in USPTO for each country in each year based on US micro patent database (sample is 1998 to 2010), the independent variables are the same as those for second column.

Appendix Table A6— Citations by foreign patents on patents approved in SIPO by China's applicants (1995–2014)

Year	Invention patents	Utility patents
1995	100	65
1996	114	62
1997	174	100
1998	201	98
1999	244	125
2000	303	198
2001	522	357
2002	667	440
2003	1,019	681
2004	1,358	851
2005	1,765	1,089
2006	2,984	1,830
2007	5,087	2,721
2008	9,183	4,084
2009	13,347	5,097
2010	20,781	7,752
2011	30,706	11,241
2012	45,364	16,132
2013	55,649	21,072
2014	71,383	23,544
Annual growth rate in different periods (%)		
1995–2004	34	33
2004–2014	49	39
1995–2014	41	36

Note: Tabulated by authors based on citations from Google Patent System.

Appendix Table A7—Hybrid negative binomial regressions on patent count: Baseline

VARIABLES	(1) Total	(2) Invention	(3) Utility	(4) Design
Sales (log)	0.437***	0.491***	0.435***	0.424***
	(0.012)	(0.024)	(0.015)	(0.019)
Export	0.115***	0.181***	0.071**	0.157***
	(0.022)	(0.045)	(0.028)	(0.036)
Wage (log)	0.082***	0.224***	0.137***	0.072*
	(0.027)	(0.050)	(0.034)	(0.042)
Subsidy rate (log)	0.003	0.045***	0.003	0.010
	(0.006)	(0.011)	(0.007)	(0.009)
Tax rate (log)	-0.073***	-0.066**	-0.085***	-0.036
	(0.017)	(0.032)	(0.021)	(0.027)
Interest rate (log)	-0.025**	0.010	-0.042***	-0.036**
	(0.010)	(0.020)	(0.013)	(0.016)
Partner tariff	-1.048***	-0.843***	-1.123***	-0.482***
	(0.078)	(0.146)	(0.115)	(0.118)
HH index	0.143	-0.087	0.541**	0.358
	(0.224)	(0.425)	(0.267)	(0.328)
Observations	1,187,140	1,187,140	1,187,140	1,187,140
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
AIC	438522	114137	270400	213959

Note: *Wage* (log), *Subsidy rate* (log), *Tax rate* (log), *Interest rate* (log) are averages at the city-industry-firm ownership type-year level (except for the firm itself). Cells with fewer than six observations are dropped. *Sales* (log) and *Export* are still firm-year level.

Appendix Table A8—Hybrid negative binomial regression on patent count: Using lagged wages

VARIABLES	(1) Total	(2) Invention	(3) Utility	(4) Design
Sales (log)	0.419***	0.454***	0.418***	0.416***
	(0.013)	(0.026)	(0.016)	(0.021)
Export	0.119***	0.172***	0.065**	0.161***
	(0.025)	(0.049)	(0.031)	(0.041)
Lag wage (log)	0.510***	0.890***	0.790***	0.541***
	(0.058)	(0.113)	(0.074)	(0.090)
Subsidy rate (log)	-0.007	0.033***	-0.009	-0.003
	(0.006)	(0.012)	(0.008)	(0.010)
Tax rate (log)	-0.067***	-0.057	-0.080***	-0.036
	(0.020)	(0.036)	(0.025)	(0.032)
Interest rate (log)	-0.018	0.017	-0.034**	-0.031*
	(0.011)	(0.021)	(0.014)	(0.019)
Partner tariff	-0.850***	-0.314*	-0.666***	-0.454***
	(0.091)	(0.171)	(0.131)	(0.140)
HH index	0.238	-0.092	0.622**	0.337
	(0.240)	(0.429)	(0.279)	(0.361)
Observations	984,517	984,517	984,517	984,517
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
AIC	368333	99218	229716	173836

Note: See Table A2. The value of wage variable is lagged by one year.

Appendix Table A9— Hybrid negative binomial regression on patent count: Using minimum wages

VARIABLES	(1) Total	(2) Invention	(3) Utility	(4) Design
Sales (log)	0.430***	0.441***	0.434***	0.435***
	(1.126)	(2.186)	(1.424)	(1.793)
Export	0.104***	0.172***	0.065**	0.148***
	(2.208)	(4.351)	(2.772)	(3.559)
Minimum wage (log)	0.318***	0.484***	0.607***	0.371***
	(4.890)	(9.569)	(6.354)	(7.597)
Subsidy rate (log)	-0.003	0.017*	-0.005	-0.013
	(0.526)	(0.978)	(0.664)	(0.859)
Tax rate (log)	0.050**	0.115***	0.026	0.053*
	(1.994)	(3.774)	(2.523)	(3.130)
Interest rate (log)	-0.012	-0.006	-0.040***	0.014
	(1.140)	(2.277)	(1.407)	(1.829)
Partner tariff	-9.156***	-6.279**	-8.354***	-4.772***
	(112.564)	(258.170)	(184.781)	(127.120)
HH index	0.358	0.085	0.486*	0.517
	(21.901)	(38.670)	(26.178)	(33.429)
Observations	1,305,376	1,305,376	1,305,376	1,305,376
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
AIC	461094	124633	283566	217422

Note: See Table A2. Minimum wages are at the city and year level.

Appendix Table A10—Impact of wage on innovations of labor intensive firms

VARIABLES	(1) Total	(2) Invention	(3) Utility	(4) Design
Wage (log)*Labor intensive dummy	0.163***	0.695***	-0.042	0.174***
	(0.038)	(0.073)	(0.052)	(0.059)
Sales (log)	0.436***	0.483***	0.433***	0.425***
	(0.012)	(0.024)	(0.015)	(0.019)
Export	0.108***	0.162***	0.064**	0.153***
	(0.022)	(0.045)	(0.028)	(0.036)
Wage (log)	0.010	-0.101*	0.184***	0.007
	(0.034)	(0.061)	(0.050)	(0.051)
Subsidy rate (log)	0.006	0.044***	0.008	0.012
	(0.006)	(0.011)	(0.007)	(0.009)
Tax rate (log)	-0.068***	-0.032	-0.082***	-0.031
	(0.017)	(0.033)	(0.021)	(0.027)
Interest rate (log)	-0.022**	0.021	-0.040***	-0.035**
	(0.011)	(0.020)	(0.013)	(0.017)
Partner tariff	-1.138***	-1.091***	-1.141***	-0.475***
	(0.082)	(0.148)	(0.120)	(0.122)
HH index	0.260	-0.090	0.597**	0.456
	(0.223)	(0.423)	(0.265)	(0.327)
Observations	1,187,140	1,187,140	1,187,140	1,187,140
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
AIC	436557	114023	266115	213652

Note: The dependent variable is patent count. Hybrid negative binomial regression is used. See Qu et al. (2013) for the definition of labor-intensive industries.

Appendix Table A11—Impact of wages on innovations in routine-intensive industries and sunset industries

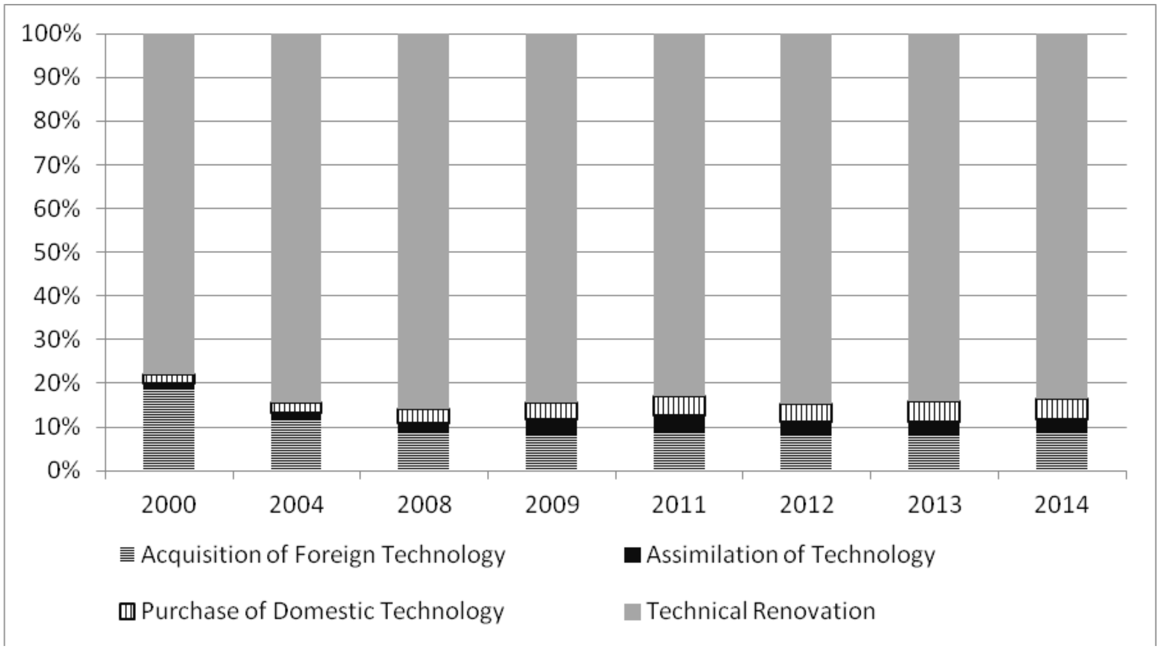
	(1)	(2)	(3)	(4)
VARIABLES	Total	Invention	Utility	Design
Panel A: Impact on routine-intensive industries				
Wage (log)*Routine	0.490***	0.992***	0.237***	0.759***
	(0.048)	(0.089)	(0.082)	(0.072)
Panel B: Impact on sunset industries				
Wage (log)*Sunset	0.040	-0.222***	-0.058	0.089
	(0.040)	(0.072)	(0.052)	(0.064)

Note: Hybrid negative binomial regression estimates. Routine industry is defined according to Autor et al. (2003).

Appendix Table A12—Impact of R&D on Patent Output: **Hybrid negative binomial regressions**

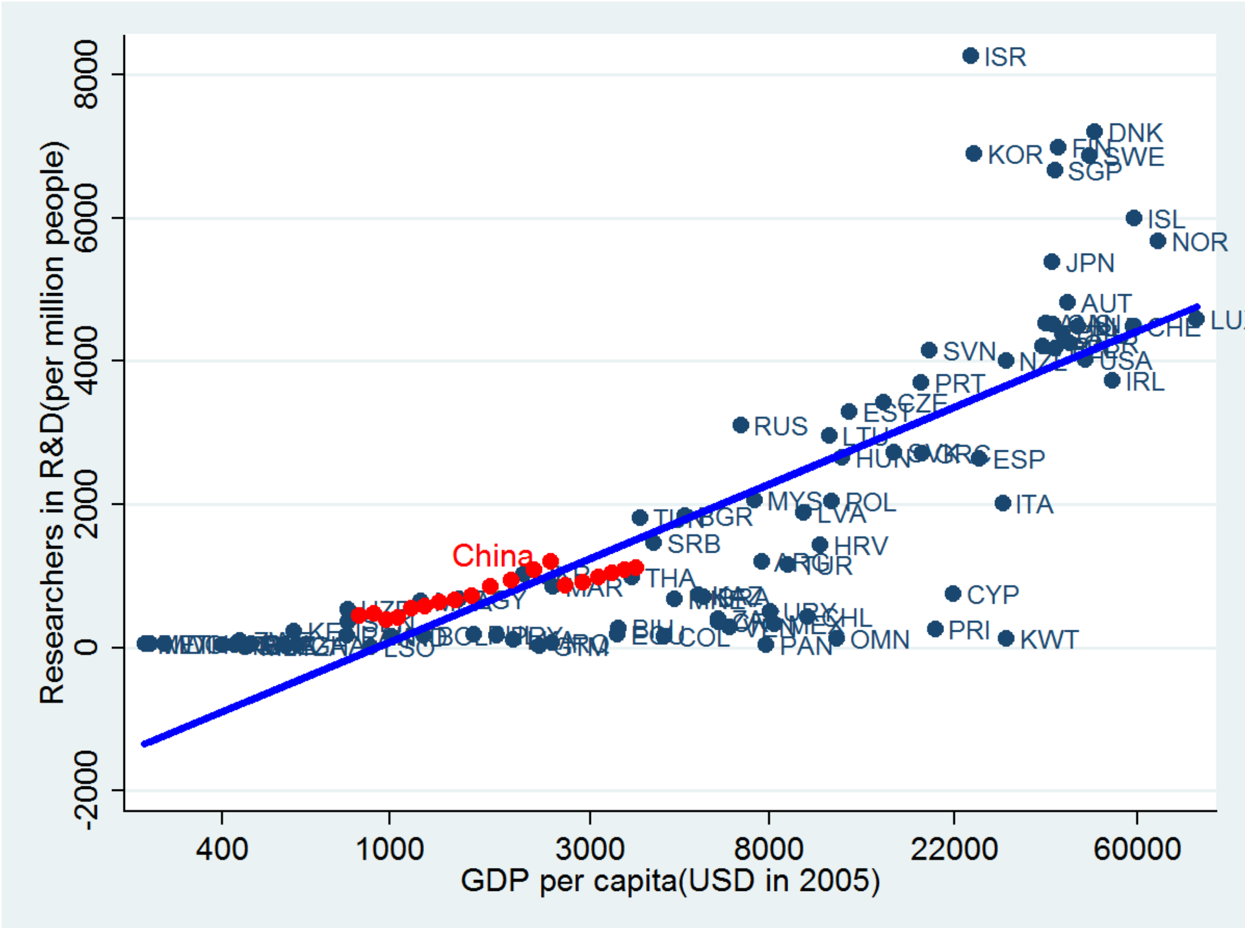
	(1)	(2)	(3)	(4)
VARIABLES	Total	Invention	Utility model	Design
R&D (log)*FIE	-0.006	-0.006	0.002	-0.014**
	(0.004)	(0.006)	(0.004)	(0.006)
R&D (log)*SOE	-0.010**	-0.017**	-0.004	-0.014
	(0.005)	(0.007)	(0.005)	(0.010)
R&D (log)	0.016***	0.016***	0.013***	0.013***
	(0.002)	(0.004)	(0.003)	(0.004)
Sales (log)	0.278***	0.314***	0.259***	0.305***
	(0.022)	(0.040)	(0.027)	(0.037)
Observations	783,229	783,229	783,229	783,229
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
AIC	298065	92655	190331	134819

Note: Since R&D data is only available for 2005–2007, we include only these three years' data in the sample.



Appendix Figure A1—Declining Contribution of Imported Foreign technology: Evidence from Above-scale Manufacturing Firms

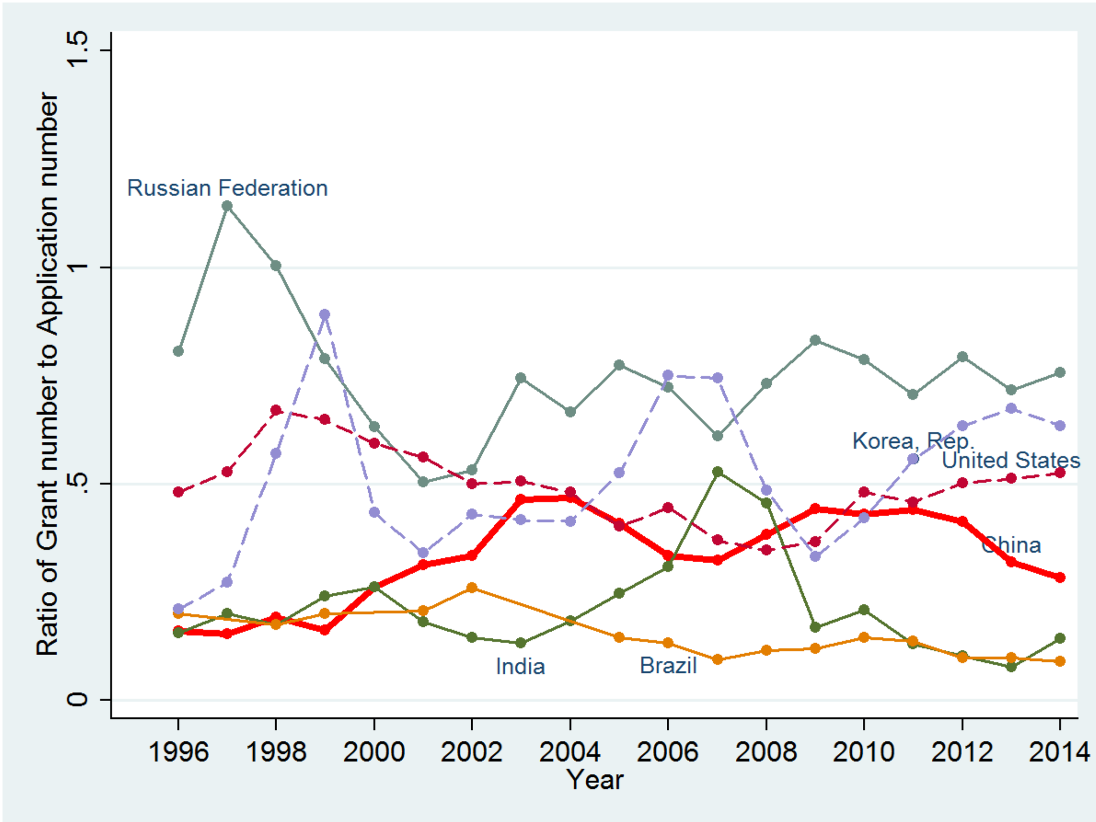
Source: China Statistical Yearbook on Science and Technology (China National Bureau of Statistics, various years).



Appendix Figure A2—Researcher Intensity Comparison

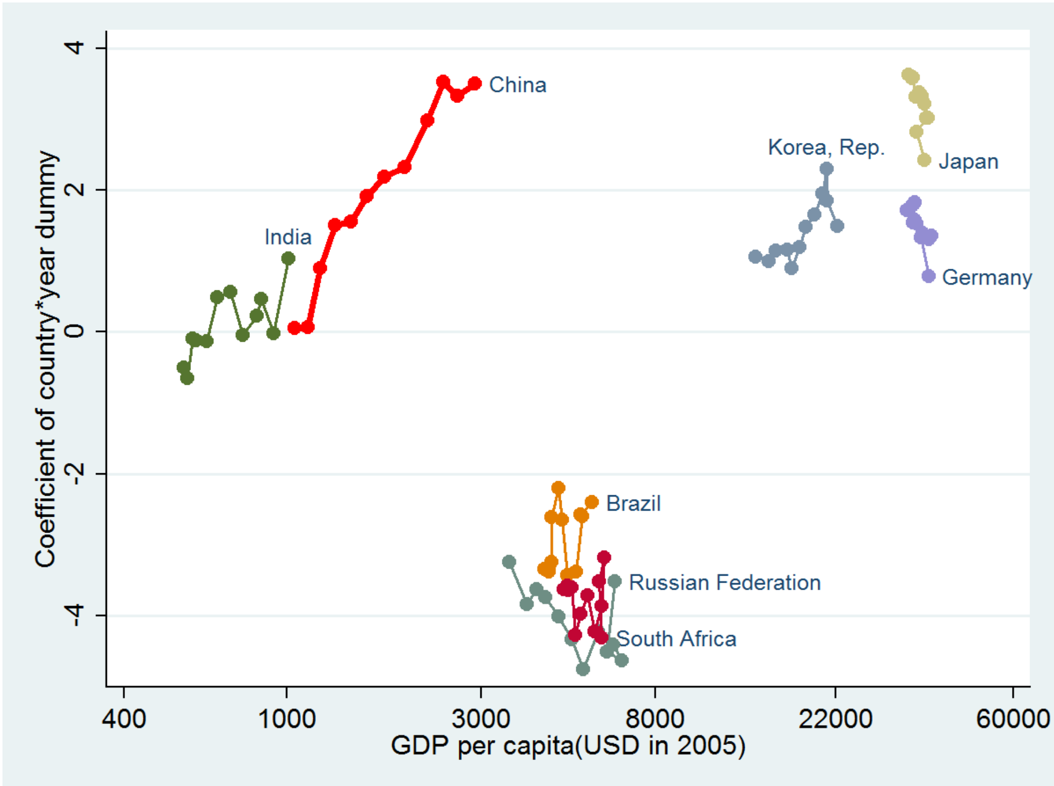
Note: Chinese data is from 1996 to 2014. For all other countries, the sample is for 2014 or the latest year available (not later than 2010). China adjusted the statistical coverage since 2009, so we see a sudden drop for China (red points in graph).

Source: World Bank.



Appendix Figure A3—Patent Approval Rate in BRIC Countries, the Republic of Korea, and the U.S.

Source: WIPO. The approval rate is defined as # patents granted in year t / # applications in year t-1.



Appendix Figure 4—Forward Citations of Patents Granted by USPTO: Cross-country Comparison

Note: Conditional plot by controlling for population, population squared, and country and year fixed effects, based on data of USPTO (1998-2010).