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Dissertation

Patenting and Innovation in China

Incentives, Policy, and Outcomes

Eric Warner

RAND CORPORATION

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This document was submitted as a dissertation in November 2014 in partial fulfillment of the requirements of the doctoral degree in public policy analysis at the Pardee RAND Graduate School. The faculty committee that supervised and approved the dissertation consisted of Charles Wolf, Jr. (Chair), Shanthi Nataraj, and Christopher Eusebi.

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Contents

Abstract

China has undergone a patenting boom, with yearly increases in patent applications averaging 34 percent. Since 2000 this has resulted in a 16 fold-increase in the annual number of patents and according to the United Nations, China's patent office has received more patent filings than any other country (UN December 11, 2012). Previous literature indicates that this trend is driven by large volumes of low-quality patents. Given this, I was motivated to understand the drivers of this trend, the impact of patenting-promoting policies, and the innovative outcomes of Chinese firms. This dissertation examines these three questions in three separate essays:

- What are the drivers of this patenting boom, and what implications exist for Chinese technical innovation?
- What are the innovative impacts of the Indigenous Innovation Policy, which is designed to promote patenting?
- How innovative are leading Chinese firms?

The first essay describes the drivers of the Chinese patent boom and their implications. Examining existing literature, I find that two key patenting drivers are the role of patent promoting policies (including patent quotas and subsidies), and increasing competition among firms. These drivers produce low-quality and high-quality patents, respectively. I also find that the effects of another patent-promoting policy, the Chinese Indigenous Innovation Policy, are not fully understood. Finally, I provide policy prescriptions for increasing the quality of patenting.

The second essay investigates the technology outcomes of the Chinese Indigenous Innovation Policy, which is a public procurement for innovation policy. Using a difference-in-difference strategy with count models and a simple pre/post-test I find that there are no economically significant effects from this policy at either the national or firm level. This casts doubt on the effectiveness of this policy to motivate Chinese technological innovation, and the impact of public policy for innovation in developing countries. These findings also raise questions regarding the viability of overall "top-down" public procurement for innovation national strategies.

In the final essay I examine how innovative leading Chinese telecommunications firms are by focusing on two Chinese firms, Huawei and Zhongxing Telecom (ZTE), and five of their international competitors. I

develop a model to measure innovativeness with an international dataset, extending previous work by Eusebi (2010) and Fay (2013). I validate this model with patent litigation award data and use it to evaluate the innovativeness of these firms. I find that Chinese firms lag behind their international brethren in innovative performance. More importantly, they do not appear to be catching up with global competitors.

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This dissertation would not be possible without the support of a number of people. This work is the product of their encouragement and guidance.

First, I would like to thank my committee chair, Dr. Charles Wolf. Charles' wisdom and guidance provided me with the impetus to explore this topic, as well as the necessary tools to complete this dissertation. Charles helped show me where I needed to develop, and how to thoroughly see the forest from the trees.

My other committee members, Dr. Shanthi Nataraj and Christopher Eusebi, were both critical to the completion of this dissertation. Shanthi provided me with invaluable guidance at multiple stages of this dissertation. She was instrumental in helping me assemble a robust modeling strategy for my second paper, and has an eye for detail that served me greatly. Chris is a man of courage who decided to serve as my committee member ten minutes after meeting me. His guidance was instrumental in helping me develop and extend his S-curve method to international data, as well as fielding my multiple novice questions regarding patents.

This dissertation would not have been possible except for generous support from Project Air Force and the National Defense Research Institute. In particular, I would like to thank Olga Oliker for supporting this dissertation with funds from the International Security and Defense Policy Center.

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Finally, I would like to thank my family and Caroline Lee for their support throughout this process. This work is a tribute to your love for me.

Any mistakes or omissions that remain in this work are my own.

Chapter 1: The Chinese patent boom – Incentives and Implications

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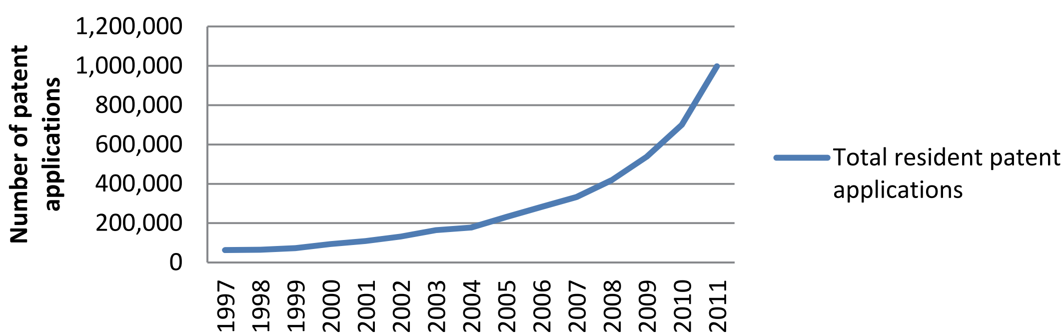
Abstract: Patent filings at the Chinese State Intellectual Property Office have increased rapidly since the late 1990's. The quality of these patents has been questioned, however. Several authors have raised concerns regarding the quality of these patents. Total Factor Productivity growth, which embodies innovation, has not kept pace, which could indicate lower quality innovations being produced. To understand this trend I examine the incentives associated with patent definitions and the patent system, market forces in the economy itself, and patent-promoting policies through a literature review. I find that patent-promoting policies, market competition, and low review standards associated with utility patents drive large volumes of patents. I also find that market competition and raising patent review thresholds are more likely to drive higher quality patents.

Introduction

Since the late 1990s, China has undergone a patenting boom. Yearly increases in patent applications have averaged 34 percent, resulting in a 16 fold-increase in the annual number of patents filed since 2000 (see figure 1 below). Concurrently, the Chinese economy has slowed since 2008, and Total Factor Productivity (TFP) growth, which embodies innovation in the economy, has declined.[1] Given that numerous studies find a positive correlation between patenting and TFP (see for instance (Maskus and McDaniel 1999; Ulku 2004; Abdih and Joutz 2006)), how can these seemingly inconsistent trends be reconciled?

Figure 1: Total annual Chinese resident domestic patent applications



To answer this question, I examine the incentives driving the patenting boom and their implications for economic and technical progress.

[1] TFP Data from (January 2013). The Conference Board Total Economy Database. C. Board.

There are many different indicators of innovation, including trademarks and research and development (R&D) investments, among others. However, patents have been used since the 1950s to measure technical change.[2] They contain information on the output of inventive activities, indicate the magnitude of technical change, and are positively correlated with firm productivity and market share (Zuniga, Guellec et al. 2009). Patents are one of the best metrics to measure technical change because they focus on the technological output developed from the innovative process (Zuniga, Guellec et al. 2009).

This paper examines the incentives to patent associated with three patenting drivers and how they vary in China. It explores the following questions:

- What are common patent incentives from intellectual property (IP) systems, the market, and patent-promoting policies in China?
- What implications do these incentives have for future Chinese technical and economic development?

This paper is the first in a series of three studies measuring inventive activity and technical change using patents. In doing so, it examines related literature and concepts, providing background and policy context for the two subsequent studies.

Innovation – measuring technical change and inventiveness

Innovation is a complex phenomenon arising from various inputs and processes. The OECD defines the central factor in the innovative process as the "innovation dynamo," or the intersection of complex factors at the firm-level that combine to create innovation (Luxembourg 2005). Because of the opaque nature of this process, identifying outputs is important for measuring the level of technical change and accumulation of knowledge.

Numerous scholars have sought to identify and measure technical change, as well as its causes and consequences. Academic research has produced a typology of innovation input and outputs (see for instance the Frascati Manual, (2002)).

Inputs include:

- *R&D Personnel*: Personnel inputs are typically measured by the number of full time equivalent employees or research-years engaged in R&D, and are subcategorized by level of education. An example of a study that uses these metrics is Anselin, et al. (1997).
- *R&D expenditures*: Measures of R&D spending include current costs and capital expenditures. Examples of research on R&D expenditures and their innovation impacts include Mansfield (1984) and Acs and Audretsch (1991).

[2] For one of the earliest papers using patent counts to measure technical change, see Schmookler, J. (1954). "Level of Inventive Activity, The." J. Pat. Off. Soc'y **36**: 883.

- *R&D facilities*: Measures of library infrastructure include library space, journal subscriptions, laboratory space, and technology or science parks. Examples of research that uses these metrics include Löfsten and Lindelöf (2002; 2005) and Anselin, Varga, and Acs (1997).

Outputs include:

- *Patents/patent applications*: Patents and patent applications are a measure of inventiveness and technical change. One of the earliest attempts to measure innovation using patents was Schmookler (1954), and more recent examples include Pakes and Griliches (1980) and Johnstone, Haščič, and Popp (2010).
- *Trademarks*: Since trademarks are used to represent a company or product, scholars typically use them as measures of the commercialization of various products. Malmberg (2005) and Mendonca, Pereira, and Godinho (2004) are both examples of research that use trademarks to measure innovation.
- *Licenses*: Licenses allow non-patent holders to use knowledge or ideas contained in patents. Data on patent licenses are useful for estimating the economic value of patents or particular ideas. Studies on licenses include Nelson (2009), Griliches (1998), and Pianta and Archibugi (1996).

Many empirical studies tend to focus on the supply of innovation inputs rather than outputs. The papers in this dissertation seek to contribute to a much more nuanced understanding of patents, and how they relate to technical change and economic growth.

The advantages of patents as an innovation measure

Each of the measures described above has advantages and disadvantages in empirical analyses of the innovative process. I focus on patents because they are an indicator of inventive activities, inventive networks, and emerging technologies, and can provide indicators of the magnitude of technological change (Zuniga, Guellec et al. 2009). Patents are also considered a metric between upstream R&D and downstream product innovation (Zuniga, Guellec et al. 2009). However, patents have both advantages and disadvantages as measures of technical change and inventiveness.

In a study of 1200 high-tech firms, Hagedoorn and Cloodt (2003) determined that a firm's patent count is a robust measure of its past technical performance. Studies of OECD data also find that most of a firm's significant inventions are patented, whether they are based on R&D or not (Zuniga, Guellec et al. 2009). Patents can also be used to evaluate the market strategy of businesses and the diffusion of technology across industries and countries (Zuniga, Guellec et al. 2009).

However, patents also have drawbacks. Important innovations are not always patented, some patents have no technological or economic value, and many patents do not lead to follow-on innovation. Many patents are never developed into actual products or innovations. As indicated by Zuniga, Guellec et al.

according to the 2005 PATVAL survey the lack of necessary production facilities or “strategic reasons” drives inventors to not use 40 percent of the patents reviewed (Zuniga, Guellec et al. 2009). This survey indicates that nearly 20 percent of the patents reviewed were meant to block competitors, and approximately 17 percent are “sleeping patents” which remain unused (Zuniga, Guellec et al. 2009). Consequently, there is large variation in patent value; some patents are valued highly, whereas others have little to no value(Zuniga, Guellec et al. 2009).

Comparing patents across industries or countries can be complex. Cross-national differences in patent laws limit the comparability of patent statistics. The propensity to patent also varies significantly across industries and technical areas (Zuniga, Guellec et al. 2009). On the one hand, firms in technical fields, such as pharmaceuticals and electronics, may create a flood of patents to deter competitors and to facilitate inter-firm negotiations. On the other hand, smaller firms may lack the resources necessary to file patents, including knowledge of patents, administrative capability, or adequate financial resources (Zuniga, Guellec et al. 2009). Zuniga, Guellec et al. show that the tendency to patent across time periods can complicate inter-temporal comparisons (2009).

Despite their drawbacks, I use patents because of their availability and ability to proxy technological change.

Patent design, use, and value

This section describes the basic design of patents, their use as a means of protecting the intellectual property of inventors, and the methods used to assess patent value.

The optimal economic design of a patent is prefaced upon the idea that an inventor’s profit from an innovation will be correlated with the societal value of this innovation, and intellectual property protection causes inventors to screen their ideas by comparing personal costs with societal value (Scotchmer 2004). This mechanism creates efficiency, as one of the key issues is that research projects have uncertain outcomes, and the design of patents must take this into account (Scotchmer 2004).

The optimal design of a patent balances private (inventor) welfare and societal welfare. If patent protection is too strong (wide patent breadth and long patent duration), then deadweight loss will result from inventions. If patents are too weak then the incentive (profits) from invention will not exceed disincentives (costs)(Scotchmer 2004). Therefore the design of patent laws determines the exact incentives for individuals to invent.

Two key elements of patent design are patent duration and breadth. Longer patent durations improve inventor welfare. In the U.S., both plant (invention) and utility patents are protected for 20 years. In

China, by contrast, invention patents have a duration of 20 years, but utility patents only receive protection for 10 years.[3]

The breadth of a patent is the minimum size of the improvements another inventor must make to obtain a non-infringing patent. A wide patent breadth requires larger improvements in subsequent inventions for them to be non-infringing. Narrow patent breadths require smaller improvements for subsequent inventions to be patented. Patents with wide breadth provide more profits to their inventors, but may stifle subsequent innovation that infringes upon the original patent. Patent breadth depends on the legal precedent in a particular country for different types of patents. For example, Chinese design patents appear to be broadly interpreted and enforced by Chinese courts as having wide patent breadth.[4]

While the prospect of profit offers an incentive to patent, there are also non-pecuniary incentives. Reputational effects are one example, and their importance varies across countries.[5] Patents are also used by firms as bargaining chips for inter-firm deals, or by smaller and younger firms to signal their capabilities to potential partners or lenders (Reitzig 2003; De Rassenfosse 2012; Neuhäusler 2012).

There are also disincentives to patent, as Cohen, Nelson, and Walsh (2000) describe. Applying for patent protection and defending patents in court can be costly, and it may be difficult to demonstrate the novelty of an invention. Furthermore, patenting may sometimes reduce a firm's competitive advantage since patent applications have extensive disclosure requirements. Inventing around a patent is legal, and may make patenting costs higher than benefits.

In theory, patents should prevent other inventors from copying existing inventions. However, several scholars have found that the costs of imitating patented inventions, across a wide range of technologies, are lower than previously thought (Mansfield, Schwartz et al. 1981). Low imitation costs ease patent infringement, creating disincentives for firms to disclose valuable inventions publicly by patenting them.

How firms actually protect their ideas and innovations

Empirical research by Cohen, Nelson and Walsh (2000) finds that patents may be the least effective method to protect intellectual property (IP). Survey data indicates several other strategies are widely preferred. One is secrecy. In many industries, keeping new ideas secret is the most favored option. Minimizing lead time is another strategy that is normally preferred. Beating other firms to market with new innovations maximizes the profits they can extract from new inventions. A third approach is

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[3] For more on optimal patent length and innovation see: Horowitz, A. W. and E. L.-C. Lai (1996). "Patent length and the rate of innovation." International Economic Review: 785-801, Gallini, N. T. (2002). "The economics of patents: Lessons from recent US patent reform." The Journal of Economic Perspectives **16**(2): 131-154.

[4] Interview with Chris Eusebi October 2013. This also agrees with other reports on the bias in Chinese courts against foreign patent holders. See USPTO (2012). Report on Patent Enforcement in China, USPTO.

[5] Interview with Chris Eusebi July 2013

bundling complementary sales and service capabilities. Businesses can often protect their profits by packaging their inventions together with complementary services or sales (Cohen, Nelson et al. 2000).

The preferred methods used to protect IP vary significantly by industry. The pharmaceuticals industry is the only sector where patent protection is found to offer substantial benefits in terms of protecting innovations and ideas. Communications equipment firms primarily prefer to reduce time to market, and computer producers typically prefer to maintain secrecy (Cohen, Nelson et al. 2000).

Sequential Innovation

Invention is often sequential, building upon essential elements of previously patented inventions. As Scotchmer (2004) notes, perhaps one of the most important contributions of patents is the boost they provide to later inventors.[6] Therefore, compensating sequential inventors under the current patent system can be difficult. This affects innovation in technologies and industries that depend on cumulative innovation, such as the pharmaceutical and information and computer technology sectors. Several scholars find that firms that are sequential innovators may rely more heavily upon patents as an indicator of technical prowess and license to operate in certain fields (Cohen, Nelson et al. 2000; Scotchmer 2004). This is particularly true in the pharmaceutical and, to a lesser degree, the Information and Communications Technology (ICT) sector (Cohen, Nelson et al. 2000).

The value of patenting

Several factors determine the economic and technical value of a patent, including patent duration, patent breadth, the extent to which the patent discloses information to competitors, and the extent to which the idea patented is novel and technically non-obvious (Reitzig 2003). Reitzig also reviews work by Rahn (1994) who shows that a patent's importance also depends on its position in a "thicket" of relevant patents.

The complexity as well as the industry and technology in which the patent is filed have value characteristics. Hall (2007) finds that patents of single ideas or products are more likely to be innovative and encourage further innovation, whereas patents involving many ideas or products, or sequential and cumulative contributions, may be less innovative. Their impact depends more heavily on the economic and technical context of the invention (Li 2010).

Scholars have developed several empirical strategies for evaluating the technological and economic value of patents. One strategy is to use patent citations (both forward and backward citations to patents

[6] Sequential, or cumulative innovations are defined by Scotchmer (2006) as those that "have a high degree of 'cumulativeness,' in the sense that each innovator builds on prior developments and discoveries."

and scientific literature) as a measure of a patent's technical impact.[7] One of the first studies to employ this approach was Carpenter, et. al. (1980). Another strategy is to measure patents' economic value as the discounted value of accumulated profits over the lifetime of the patent (Nordhaus 1967; Langinier and Moschini 2002; Scotchmer 2004). The licensing revenues associated with particular patents have also been used as a measure of their economic value.[8]

Another measure of economic and technical impact used in the literature on patents is the number of different markets in which the patent application has been filed. The highest standard is the Patent Cooperation Treaty (PCT), a patenting treaty allowing a patent to be filed and protected in 148 countries worldwide (WIPO 2014). Given the difficulty of being awarded these patents, they typically indicate higher levels of originality. Identical patent applications filed in the US, Japan, and the European Union are known as triadic patents and typically indicate high value (Sternitzke 2009). Patents filed in a home country and later in larger markets (US, Japan, EU) are known as dyadic patents, and also tend to be valuable.

Firm size and industry effects

Firm size and industry are also related to the quality and number of patents. Smaller firms are more likely to use patents as an indicator of innovative ability when seeking outside investment or business opportunities (Cohen, Nelson et al. 2000). Patents of economic and technical value are more likely to emerge in the pharmaceutical, medical device, and to a lesser degree the ICT sector. Pharmaceuticals and medical device manufacturers are more likely to patent because products in these sectors require early disclosure, lengthy and expensive research and development cycles, and are easily replicable by competitors (Lehman 2003). The ICT sector is largely a cumulative innovator, and many firms can amass large patent libraries and use these in inter-firm deals or to block other firms from creating infringing patents in valuable technical areas.[9]

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[7] For a full list of technical and economic value metrics see Squicciarini, M., H. Dernis, et al. (2013). Measuring Patent Quality: Indicators of Technological and Economic Value, OECD Publishing.

[8] Data on licensing rates for different types of inventions can be used to estimate the value of various inventions as well as the non-obviousness of an invention. See McNelis, J. T. New Designs: Licenses May Be Evidence of the Nonobviousness of an Invention, Fenwick and West LLP.

[9] For more on the role of patents in the ICT and computing sectors being used for inter-firm deals see Hall, B. H. and R. H. Ziedonis (2001). "The patent paradox revisited: an empirical study of patenting in the US semiconductor industry, 1979-1995." RAND Journal of Economics: 101-128. Reitzig, M. (2003). "What determines patent value?: Insights from the semiconductor industry." Research Policy **32**(1): 13-26, De Rassenfosse, G. (2012). "How SMEs exploit their intellectual property assets: evidence from survey data." Small Business Economics **39**(2): 437-452.

Intellectual property systems and innovation

Patents are defined by, and exist within, wider intellectual property (IP) systems. These systems establish patent breadth and duration, as well as standards for originality. These systems also provide enforcement of patents and intellectual property rights (IPR). An appropriate IP system encourages private investment in new knowledge, while providing a channel for diffusion of technologies throughout the economy. It also has other positive economic impacts, including increased inflows of foreign technology and increased foreign direct investment (FDI).[10]

Because IPR protection is the primary incentive for patenting, previous literature on patents has examined the linkage between innovation and IPR protection. Multiple researchers show that innovation and IPR strength have an inverted U-shaped relationship (Park 2007; Furukawa 2010; Gangopadhyay and Mondal 2012). However, this relationship depends upon the level of economic development in a country. Schneider (2005) empirically demonstrates that IPRs have stronger effects on domestic innovation in developed rather than developing nations. Chen and Puttitanun (2005) develop this further and find that as the technical ability of a country increases, the strength of IPRs should first decrease and then later increase to encourage innovation.[11]

Markets, innovation, and economic effects

A significant body of literature finds that economic growth and innovation are interdependent. On one hand, market forces can promotes inventiveness, and on the other, innovation promotes development. In the economic theory literature, models of growth and innovation fall within two paradigms: theories of exogenous versus endogenous knowledge creation. The Neo-classical growth model by Solow (1956) treats new knowledge as an exogenous public good.[12] Endogenous growth theory, as proposed by Lucas (1988) and Romer (1990), treats innovation as endogenous, with new innovations displacing old ones, in the process of “vertical innovation” (Uppenberg 2009).

[10] Previous research also shows increased foreign inflows of technology with increases in IPR protection. Branstetter et al. (2006) finds that increased IPRs in developing countries drives increased technology transfers from US MNCs to their R&D labs and affiliates in those countries. Adams (2010) shows that stronger IPR is also correlated with increases of FDI.

[11] Chen and Puttitanun also point out that this agrees with Acemoglu, et al. (2002) which indicates that developing countries should encourage technology adoption, while more developed countries should adopt strategies to encourage innovation. See Acemoglu, D., P. Aghion, et al. (2006). "Distance to frontier, selection, and economic growth." Journal of the European Economic Association **4**(1): 37-74.

[12] The Solow growth model is based on the equation: $Y = AK^{a}L^{1-a}$ where the output (Y) is a function of A (knowledge/TFP), K (capital) and L (labor).

Incentives from the market

Arrow (1962) was one of the earliest to show theoretically that market structure can provide incentives to innovate. Later work in the endogenous growth paradigm provides empirical evidence of this. Aghion and Howitt (2005) find that the degree of market competition has varying effects on innovation based upon a country's level of technological development (Aghion and Howitt 2005). In their model, competition increases innovation when firms are near the technology frontier (more advanced technology), but decreases it far from the frontier (less advanced technology). At the frontier, firms are incentivized to innovate more frequently to escape competition and decrease the number of firms at similar competition levels (Aghion, Bloom et al. 2005; Aghion and Howitt 2005). These authors term this the "escape competition effect." However, Aghion and Howitt also point out that the concentration of a few highly innovative firms may increase the barriers to market entry from laggard firms while reducing innovation from sector leaders. These authors agree that the relationship between innovation and competition is non-monotonic, and can be characterized as an inverted-U.

The relationship between patents and economic growth: the exogenous growth paradigm

In exogenous theories of economic growth, technical change or new knowledge creation is embodied in the residual left over after accounting for other measured inputs (typically capital and labor). This variable is known as Total Factor Productivity (TFP). As Uppenberg notes, growth in this model has constant returns to scale, but is hampered by diminishing returns to capital and labor inputs (2009). The only way to increase output is to continuously increase the stock of knowledge (Uppenberg 2009). Empirical research by Solow finds that approximately 87 percent of US output per man hour from 1909-1950 was attributable to technical change (1957). TFP has also been empirically shown to drive the long-run income differences of countries (Easterly and Levine 2001).

TFP is an agglomeration of several different factors and its determinants are varied. Previous research by Isaksson synthesizes the TFP literature to conclude that the determinants of TFP include, but are not limited to: "education, health, infrastructure, imports, institutions, openness, competition, financial development, geographical predicaments, and absorptive capacity" (2007). Several themes among these determinants emerge, one of which is knowledge creation and dissemination, which has a direct effect on TFP (Isaksson 2007). In empirical studies, knowledge stock and creation are frequently represented by patent counts.

There is considerable agreement in the scholarly literature that TFP is positively correlated with patenting, although scholars find correlations of different magnitudes. Abdih and Joutz (2006) find that the stock of knowledge, proxied by patents and patent applications, has a limited and imprecise long-term positive relationship with TFP. Ulku (2004) shows that patent applications have a strong relationship with per capita GDP and a positive relationship with TFP. Madsen (2008) shows that international patent stock, along with knowledge spillovers from imports, is an important determinant of TFP in OECD countries between 1883 and 2004.

Multiple researchers show a country's level of domestic knowledge and the technological areas in which it is concentrated enables assimilation of foreign technical knowledge, also referred to as 'absorptive capacity' (Cohen and Levinthal 1990; Evenson and Westphal 1995; Aghion and Howitt 2005). In more recent work, Fu, et al. (2011) finds that the "benefits of international technology diffusion can only be delivered with parallel indigenous innovation efforts and the presence of modern institutional and governance structures and a conducive innovation system." Empirical work confirms this effect in China. Liu and White (1997) use data from 29 Chinese manufacturing industries over a five year time period to show that innovation is driven by concurrent investments in foreign technology and absorptive capacity resources (proxied by R&D personnel).

Absorptive capacity is particularly important in cases where productivity growth is primarily driven by foreign technology transfer. Other research (Eaton and Kortum 1996) empirically shows that even in OECD countries (excluding Germany, Japan, the US, France, and the UK) foreign ideas account for approximately 90 percent of productivity growth. These empirical findings are consistent with work by Crafts (2012) suggesting that promoting technical spillovers is likely more important than fostering leading edge inventions in many countries.

The relationship between patents and economic growth: the endogenous growth paradigm

Endogenous growth theory treats innovation as a resource that can be developed from investments by economic actors. It states that new innovations will supplant old ones through a process of "vertical innovation" (Uppenberg 2009). Endogenous models allow knowledge creation from two sources: as a spillover from fixed investment; and as a result of investment in knowledge creation. Following work by Lucas (1988) and Romer (1990), Aghion and Howitt (2005) have contributed the most recent advancements in this theory.[13] They find that economic development increases as the impact of innovation grows, and that intellectual property protection is important for growth because imitation decreases the incentives to develop new knowledge, which harms overall growth. Aghion and Howitt also argue a key factor for a country is its "distance to the technological frontier" which predicates the proper policy designs and institutions enabling economic growth (2005).[14]

The Aghion and Howitt model also has several implications for long run economic growth across nations. The authors note that long-run growth rates among most rich and middle income countries belong to one group, or "convergence club" (Aghion and Howitt 2005). Cross-sector spillovers allow relatively laggard economies to catch up to the current technological frontier through innovation (Howitt 2000; Aghion and Howitt 2005). These national conditions determine the relative productivity level of a

[13] The earliest work in this theoretical vein is Schumpeter who coined the term "creative destruction." See: Sweezy, P. M. (1943). "Professor Schumpeter's theory of innovation." The Review of Economics and Statistics **25**(1): 93-96, Schumpeter, J. A. (2013). Capitalism, socialism and democracy, Routledge.
[14] Aghion and Howitt note that this is originally from Gerschenkron in *Economic Backwardness in Historical Perspective* (1962) which argues that by adopting appropriate institutions, laggard economies could catch up with advanced economies.

country, and thus its long run economic growth rate (Aghion and Howitt 2005). Endogenous growth models accommodate the ability of economic actors to influence economic growth by enacting policies that promote knowledge creation. In other words, individual decisions to create knowledge and invest drive economic growth, and can be incentivized by policy (Crafts 2012).

The case of China

Over the previous decade, China has experienced a patenting explosion. To make sense of its implications, several factors must be considered:

- the scale and scope of the Chinese patenting boom,
- the rules and regulations defining Chinese patents,
- the enforcement of patents in China,
- the patent-promoting policies in use,
- the degree of competition in Chinese industries,
- the relationship in China between patents, TFP, and economic growth.

The Chinese patent boom

Chinese patents have been growing rapidly since the late 1990s. In 2011, patent application filings at the State Intellectual Property Office (SIPO) were the highest in the world (UN December 11, 2012). Though the volume of patent filings has increased substantially, several authors have questioned the quality of these patents (McGregor 2010; Zhou and Stembridge 2010; Liang 2011; Prud'homme 2012).

Chinese patent law defines three types of patents: Invention, utility, and design (Ministry of Commerce 2014).[15] The US and other technologically advanced nations typically do not have utility patents. Invention patents are of the highest innovative quality, and utility model patents include significantly less innovative content. Design patents, which typically lack technically innovative content, are excluded from this analysis. Figures 2, 3, and 4 show trends of applications from Chinese residents, applications from foreign inventors, and patent grants, respectively. One clear trend from these figures emerges: though patent filings have increased rapidly, the majority of filings are utility patents from domestic Chinese inventors, which are typically of a lower quality.

[15] These patents are defined by the Chinese government as follows: "'Invention' means any new technical solution relating to a product, a process or improvement thereof; 'Utility model' means any new technical solution relating to the shape, the structure, or their combination, of a product, which is fit for practical use. 'Design' means any new design of the shape, the pattern or their combination, or the combination of the colors with shape or pattern, of a product, which creates an aesthetic feeling and is fit for industrial application." Ministry of Commerce. (2014). "Definition of Invention, Utility Model and Design." Retrieved November 5, 2014, from http://www.chinaipr.gov.cn/guidespatentarticle/guides/agpatent/agpintroduction/200612/234398_1.html.

Figure 2: Annual resident Chinese patent applications

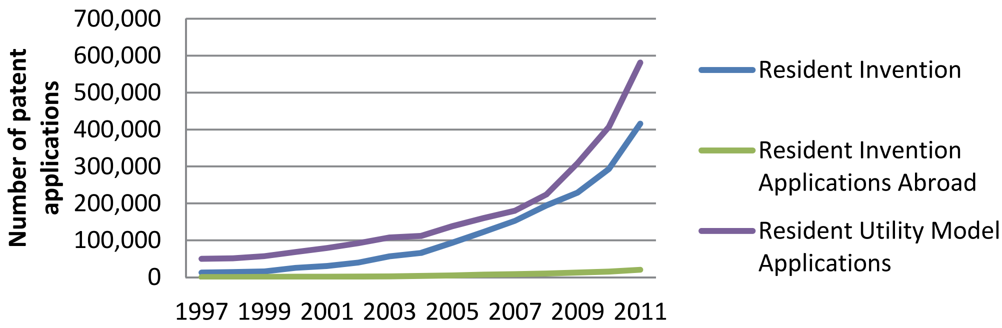


Chart assembled from World Intellectual Property (WIPO) data

Figure 3: Non-resident Chinese patent applications

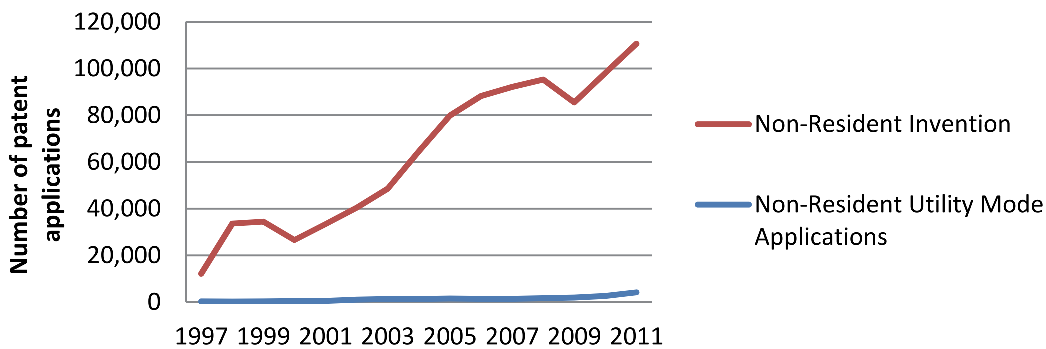


Chart assembled from WIPO data

Figure 4: Annual patent grants

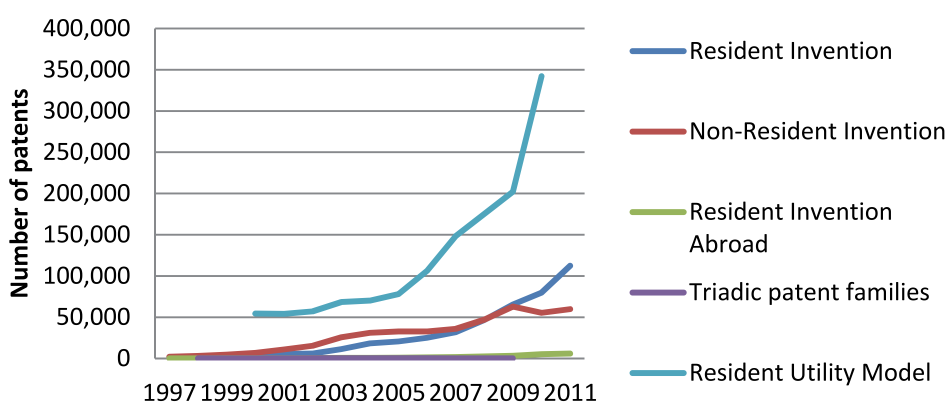


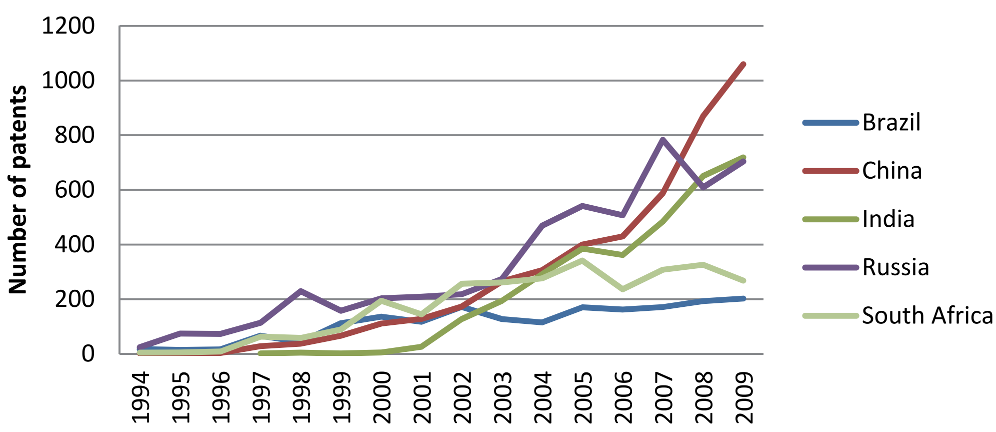
Chart assembled from WIPO data

Several trends are apparent in Figures 2, 3, and 4. First, the share of utility model applications and grants has remained a large proportion of total resident Chinese patent applications and grants.[16] Second, fewer than half of utility patent applications are approved, which likely indicates that large numbers of applications do not meet required originality thresholds. Third, the utility patent phenomenon is almost exclusively due to domestic Chinese inventors. Finally, resident invention patent grants at SIPO have only recently surpassed foreign invention patent grants, which suggests that the number of high-quality domestic innovations has only recently surpassed that of foreign innovations.

Comparing domestic and foreign patenting activity by resident Chinese inventors reveals two trends. The numbers of Chinese foreign patents, foreign applications, and triadic patents are very small in comparison to domestic patents and do not exhibit the same growth patterns as Chinese utility patents. As discussed earlier, applications to foreign patent offices' typically signal higher-value patents. The small number of Patent Cooperation Treaty (PCT), triadic, and dyadic patents filed by Chinese inventors could indicate low levels of innovativeness.

Though lagging behind foreign patenting at SIPO until recently, China's patenting performance is superior to that of other developing nations. Comparisons across the BRICS nations—Brazil, Russia, India, China and South Africa—reveal stark differences. Focusing on PCT applications and foreign patent families (patents filed by residents in other countries) controls for the low strength of IPR or low thresholds of originality domestically. In 2003, PCT grants to Chinese investors outnumbered those to all other BRICS nations, except Russia. China surpassed Russia in 2007, and now foreign patents granted to Chinese inventors far exceed those in other BRIC nations, as figure 6 shows.

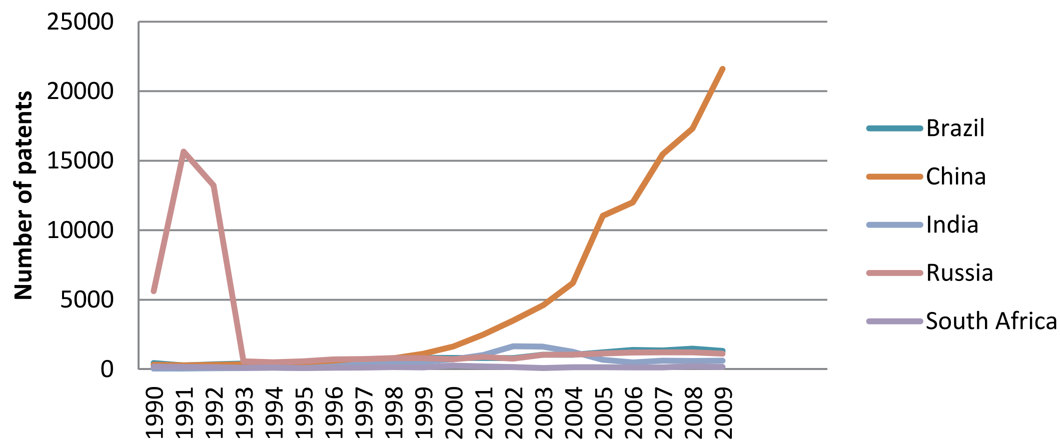
Figure 5: BRICS PCT patent grants



Note: Data prior to 1994 was not available. 2010 and 2011 data were omitted due to the lag time associated with approving patents, which can take up to 4-6 years. Chart assembled from WIPO data.

[16] From 2004-2010 the ratio of utility patent grants to invention patent grants was approximately four to one.

Figure 6: BRICS foreign patent grants



Note: 2010 and 2011 data were omitted due to the lag time associated with approving patents, which can take up to 4-6 years. Chart assembled from WIPO data

The rules, regulations, and laws defining Chinese patents

Three key features of patents—their duration, breadth, and review standards—largely shape the incentives facing inventors.

- **Patent duration.** Invention, utility, and design patents have different durations of protection. Invention patents require the highest levels of originality, are thoroughly examined, and expire after 20 years. Chinese Utility patents protect the inventor for 10 years.[17] The US provides protection for invention patents for 20 years and design patents for 14 years. Chinese patents are all first-to-file, which means that the inventor who files first for a patent is granted the patent, even if a later applicant can show that they developed the particular invention earlier. Given these patent durations, if an inventors' idea is of sufficient quality, then the inventor should be incentivized to file an invention patent, rather than a utility patent.
- **Patent breadth.** Unlike patent duration, which is explicitly stipulated, patent breadth depends on a country's patent system and legal precedent. Evaluating the breadth of Chinese patents is difficult due to a lack of empirical papers examining this topic. Based on interviews with subject matter experts, Chinese patents may be broader than US patents, particularly when the patent holders were Chinese residents.[18] Such wide patent breadths should incentivize patent filings by resident Chinese inventors, but create disincentives for foreign inventors in China.

[17]The State Intellectual Property Office states that utility patents are only subject to a preliminary examination, versus examinations for novelty, inventiveness, and industrial applicability which invention patents undergo. For more on the Chinese utility model patent system see Moga, T. (2012). China's Utility Model Patent System: Innovation Driver or Deterrent, US Chamber of Commerce.
[18] Interview with Chris Eusebi October, 2013.

- **Review standards.** The review standards to which patent applications are subjected vary significantly, both across and within patent types. All invention patents undergo a substantive review in which all public information relevant to the invention's novelty is examined. Utility patents do not undergo such intensive review. Historically, there has been a low bar for invention originality, which affected the types and quality of inventions submitted as for patents.[19] US patents also undergo substantive review, but have higher standards of originality. This is best illustrated by examining the patent application to grant ratios for a specific technological area – induced pluripotent stem cell technologies. In the US and Japan 8% of applications were granted, in Europe 9%, and in China 22% of all applications (Roberts, Wall et al. 2014).[20]

Examining the three defining characteristics of Chinese patents shows that they help to explain the large adoption of Chinese utility patents. Though they have a short duration, utility patents have low originality thresholds and lack a substantive review of previous information which is relevant to the patent's originality claims. This likely incentivizes Chinese inventors to file inventions with lower innovative content as utility models.

The production of large numbers of lower quality patents may still play a positive role in technical development. Maskus and McDaniel (1999) provide empirical evidence that utility patents positively impacted Japanese productivity growth. Kumar (2003) argues that utility models helped foster a culture of innovation and patenting in East Asian economies. Breznitz and Murphree (2011)argue that China is, and should be, engaged in incremental process innovations in highly developed technology fields that will later lead to new product innovation. Utility model patents may be one way to accomplish this.

Changes in Chinese patent laws

Another potential driver of China's recent patent boom could be the amendments to Chinese patent laws in 2000 and 2009 which increased thresholds for patent grants. Following policy changes in 2001 and 2009, there were minor and major increases, respectively, in both patent applications and grants.[21] However, empirical evidence shows that as innovative inputs increased, innovative outputs (patenting)

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[19] The relatively low quality of Chinese patents has been noted by several authors. See: Liang, M. (2011). "Chinese Patent Quality: Running the Numbers and Possible Remedies." J. Marshall Rev. Intell. Prop. L. **11**: i.

[20] Patent processing by SIPO is also skewed towards domestic inventors, indicating bias in review standards. In a study of the US and Chinese patent offices, Yang (2008) finds the Chinese patent office is more likely to grant patents to domestic rather than foreign inventors. Research by Liegsalz and Wagner (2013) also show that foreign applicants receive grants more slowly than their Chinese counterparts. See: Yang, D. (2008). "Pendency and grant ratios of invention patents: A comparative study of the US and China." Research Policy **37**(6): 1035-1046. Liegsalz, J. and S. Wagner (2013). "Patent examination at the State Intellectual Property Office in China." Research Policy **42**(2): 552-563.

[21] Hu and Jefferson (2009) assert that an important factor in increased Chinese patent grants in 2000 was the change in Chinese patent law in that same year. Conversely there was not similar increases in 2009, but rather in 2010 and 2011, when patent applications increased by 28 and 42 percent, respectively. Author's calculations from World Bank World Development Indicators data on resident patent applications.

increased at an even faster rate. Li (2012) empirically shows that patent law changes and increases in R&D cannot explain increases in patenting since 2000.

Patent enforcement

One reason why the 2000 and 2009 laws may not have incentivized patenting is that enforcement of these laws has been limited. As Yasong (2008) describes, Chinese judicial protection of patents is "one step behind, but evolving."[22] Patenting requires public disclosure of ideas. With a weak enforcement regime, inventors cannot be assured their monopoly rights over these ideas will be protected. They therefore have an incentive to opt for secrecy or other methods to ensure that they are able to capture the profits generated by their inventions (also referred to as the appropriability of their inventions).

As several studies have shown, Chinese failure to enforce IPR rules remains a major hurdle (Yueh 2009; Hu 2010; Liang 2011). Enforcement is typically at the local level in China, where the judicial system has been accused of local protectionism and discriminatory treatment against foreign rights' holders (USPTO 2012).

Empirical work on Chinese patent enforcement shows that it lags behind that of developed nations, but has rapidly increased protection. The IPR protection index assembled by Park (2008), of which IPR enforcement is a component, shows China ranked 32nd in the world in 2005.[23] This is a dramatic improvement over previous years; China ranked 59th in the world in 2000, and 69th in 1995.

Suggestive evidence of the relatively weak enforcement of patent rights is provided by invalidation rates[24] of Chinese invention and utility patents. Invalidation rates are displayed in Table 1. Moga (2012) shows that invalidation rates should be lower for invention patents which have higher originality standards and more thorough reviews. Utility patents should have higher invalidation rates, given their lack of substantive review. As shown in the table, invalidation rates between these two types of patents are strikingly similar. This indicates that infringing utility patents are difficult to invalidate, which creates significant weakness in enforcement of overall patent rights.

Table 1: Results of 7,534 resolved requests for invalidation of patents 2000-2008

Type of patent	Validity upheld (%)	Partially invalidated (%)	Wholly invalidated (%)
Invention	29.72	16.47	25.39
Utility model	31.82	11.53	33.26

Table taken from Moga (2012) pg 20. Note that not all requests for patent review are resolved and many cases are settled

[22]For further details on Chinese judicial patent protection see: Yasong, L. and M. T. Connor (2008). "An overview of the judicial protection of patents in China." Journal of Intellectual Property Law & Practice **3**(3): 163-173.
[23] This index incorporates patentability of various technologies, international intellectual property treaty membership, the strength of enforcement mechanisms, and restrictions on patent rights. See: Park, W. G. (2008). "International patent protection: 1960–2005." Research Policy **37**(4): 761-766.
[24]Invalidation of patent protection occurs when a third party successful challenges the originality of a standing patent in a court case.

outside of court.

Comparing invalidation requests among China and other countries could also indicate relatively low expectations of weak patent enforcement. In 2009 less than 5% of patents filed with the European Patent Office were subject to invalidation requests (Wilding 2010). In comparison, invalidation requests comprised less than 1% of patents filed at SIPO in 2010 (Prud'homme 2012). In 2001, Japan, which has invention and utility patents, saw invalidation requests of 4% of granted patents. In 2002 invalidation requests at SIPO were approximately 1.3% of total patent grants (Sun 2004). During both time frames, Chinese invalidation requests were significantly lower than other nations.

Other patent-promoting policies

The Chinese government has developed other policies to promote the creation of new technology. These include three types of policies which attempt to stimulate patenting of and demand for high-technology products:

- *Patent subsidies*: Chinese patent subsidies, which are sometimes coupled with rewards for granted patent applications, have been shown to increase the volume but reduce the quality of Chinese patents. Li (2012) points out that a significant amount of new patenting by Chinese firms can be explained by these subsidy policies, which are administered at the provincial or municipal level.[25] Using the city of Zhangjiagang between 2004-2007 as an example, other authors (Lei, Sun et al.) show that increases in patent subsidies are positively correlated with increases in invention patent applications. However, these patents are of lower quality, as measured by decreasing numbers of claims per application.[26] These authors also show that prior to implementation of this policy, inventors were not constrained by patenting costs. Following policy implementation, Chinese inventors produced more patents of lower quality to capture these subsidies. Their research suggests that these firms are responding to subsidy policies strategically, by producing lower-quality patents.
- *Setting quotas*: Patent quotas, which are typically set by provincial or municipal governments, specify patent application targets for a year. These policies have similar effects on patenting by driving patent volume of lower overall quality. Lei, Sun et. al. (2012) show this empirically, with inventors spreading out their patent claims among more applications by evaluating the average number of claims per patent. These authors show that this policy drives increased patent application numbers of lower overall quality.
- *Stoking demand for Chinese IP*: The Chinese government has also instituted policies that tie government procurement with ownership of Chinese intellectual property. One example, known as the Indigenous Innovation Policy, creates demand for innovative products by

[25] Actual subsidy amounts vary based upon province/municipality, the type of patent (invention/utility/design) and whether the application is domestic or in a foreign country. Examples include Shanghai, where domestic invention patents receive 3,000 yuan, and 10,000 yuan for each foreign country filed in, limited at 30,000 yuan. See: Kriegel, J. (2012). Strategies to leverage Chinese patent subsidies Intellectual Property Magazine.

[26] A patent claim defines the scope of protection conferred by that patent. In general, the more claims in a patent, the larger the protection offered.

providing preferential government procurement to firms that own Chinese intellectual property (Zeldin). The effects of these policies are poorly understood. I contribute to the literature by exploring them in greater detail in the second paper of this dissertation.

Chinese market incentives to innovate

Another factor which may be driving the surge of Chinese patenting is increased competition (Aghion, Bloom et al. 2005). Several empirical results provide support for this assertion.

Table 2 provides insight into how the level of market competition has changed China. OECD data shows that competition in Chinese industries, measured by market concentration, has increased from 1998 to 2007. This increase in competition coincides with rapid growth of Chinese patenting.

Table 2: Market concentration in the industrial sector

	1998		2007	
	Number of industries	%	Number of industries	%
Highly concentrated	88	15	34	7
Moderately concentrated	70	12	36	7
Unconcentrated	433	73	453	87
Total number of industries	591	100	523	100

This table is taken directly from the OECD Economic Survey: China (2010). These metrics are assembled based upon the Herfindahl-Hirschman index. Chinese Industrial sectors are organized on 4-digit ISIC industrial codes and thresholds for the three levels of concentration correspond to US Department of Justice standards for industrial concentration.

Empirical research provides further evidence that competition is a major driver of Chinese patenting. Du and Chen (2010) show, using R&D expenditures data from Chinese manufacturing firms, that market competition and innovation levels follow an inverted U-shaped relationship. This work, combined with the general trend of rising competitiveness shown in Table 2, suggests that competition could be a significant driver of patenting in China. Hu (2010) uses SIPO and USPTO data to show competition between foreign firms accounts for nearly 40 percent of the yearly increase in foreign patenting in China. This study provides further evidence that a major share of patenting in China is from “escape competition.”

Chinese innovation, total factor productivity, and economic growth

Previous research has shown that increases in patenting are correlated with increased TFP, and TFP is a major determinant in long-run growth. As shown previously by Ulku, Abdih and Joutz, and Madsen, patents are positively correlated with TFP. TFP growth has been shown by Aghion and Howitt and others to explain the differences in long run economic growth among countries. Thus, with increased patenting we should expect to see an increase in TFP.

As Chinese patenting has increased, Chinese investment in R&D has been increasing. From 2008 to 2011 Chinese gross expenditure on research and development (GERD) as a percentage of GDP increased annually by 7.1 percent on average.[27] Hu and Jefferson (2009) also show that Chinese R&D funding has exceeded 1% of GDP, one of the few low income countries in this category. With such high investments in R&D, we should expect to see higher TFP growth.

However, as Chinese patenting and R&D have risen, Chinese TFP growth has slowed. From 2000 to 2007, TFP growth averaged 4.9 percent and then dropped to 2.3 percent from 2008-2011.[28] This decline in TFP growth was concurrent with an average of 30 percent annual increases in patent applications from 2008 to 2011.[29] Though TFP is associated with a number of determinants, this drop in TFP could be due to low patenting quality. Such low quality not only affects current TFP, but also the ability to absorb external innovation and drive further growth of TFP.

Both foreign and domestic sources contribute to Chinese TFP growth. Empirical research shows that Chinese TFP has been driven primarily by technological progress from abroad. Studies by Zheng and Hu (2006) show historical Chinese TFP growth is driven by technological progress rather than efficiency gains. It appears that these technology gains are primarily from imported equipment, rather than domestic inventions or efficiency gains. Such absorption limits economic growth by not promoting self-learning and development of new efficiencies.

Other empirical research also shows the importance of domestically developed technologies in developing productivity. Li (2011) uses a panel dataset of Chinese SOEs in 21 high-technology sectors during 1995-2004 to suggest that Chinese firms more easily absorb domestic, rather than foreign technical knowledge. These findings show that the creation and dissemination of domestic technologies are important to drive economic growth.

The lack of TFP growth indicates that TFP from these foreign or domestic sources is lagging. This could be due to lower quality innovations being developed. Lower quality innovations would not allow for assimilation of more advanced foreign technologies and would degrade the contribution of new domestic innovations on TFP growth.

[27] Author's calculations using OECD (2013). Main Science and Technology Indicators.
[28] TFP estimates vary by source and estimation method. The data used in here is meant to be illustrative. (January 2013). The Conference Board Total Economy Database. C. Board.
[29] Author's calculations using WIPO data.

Summary

This paper summarized patent incentives from the patent system and market forces, and how those incentives affect patenting, innovation, and economic growth in China. Patent incentives come from three primary drivers:

- patent definitions and the patent system,
- market forces in the economy itself, and
- patent-promoting policies.

Effects of these incentives on patent quantity and quality are summarized in table 3, with green indicating a positive effect and red a negative effect.

Table 3: Incentives and their effects on patent volume and quality

Incentive/Effects	Increased patent volume	Increased patent quality
Patent definitions/patent system	Previous patent law changes unlikely cause of patent boom	Enforcement of current standards would incentivize increased patent quality
Patenting promoting policies	Likely driver of increased patent volume	Work by other researchers shows that patent quality decreases under these policies
Market forces	Competition is shown to be driver of patenting	Competition-driven patents are likely of higher quality, as the profits associated with innovation that provides competitive advantage are higher than those provided by patent-promoting policies

The Chinese patenting boom

Empirical trends show that Chinese patenting is largely concentrated on the production of lower-quality innovations recognized as utility models. Grants of Chinese invention patents to Chinese inventors have only recently surpassed Chinese patents granted to foreign inventors. Patent grants to Chinese investors from foreign patent offices, which would indicate increased economic and innovative value, have not seen the same growth, totaling only 5,817 patents in 2011.

Incentives from the patent system

Knowledge creation from patenting is incentivized by increasing the patent duration or breadth and strengthening enforcement of IP standards.

The basis of this protection is the legally defined duration and breadth of patent protection. As described earlier, the length of Chinese invention patents is 20 years, and utility patents 10 years. Chinese utility patent protection is considerably shorter than the analogous US standards. Additionally Chinese patent breadth, or minimum improvements to an invention necessary to be granted a non-infringing patent, are generally perceived to be larger than their western counterparts. Chinese thresholds of originality for patents are perceived to be lower, creating a strong incentive to file utility patents.

The current Chinese IP system appears to be aligned with dissemination of innovation, rather than creation of it. This is largely due to the inconsistent and relatively weak enforcement of IP rights. Relatively low patent originality thresholds and weak IPR enforcement are consistent with a country that is not near the technology frontier and has a relatively low level of technology development. As China approaches the global technology frontier in multiple sectors, the incentives to strengthen patent protection also increase. The current IPR system provides economic growth through dissemination of new technologies, but has drawbacks in that it may limit incentives to innovate by inventors.

It is unlikely that strengthened IPRs have played a role in incentivizing the Chinese patent boom. Amendments to Chinese patent law in 2000 do not appear to account for patenting increases in subsequent years (Li 2012). Patent law amendments in 2009 appear to be correlated with small increases in patenting over previous years, but there have been no robust empirical analyses examining the effects of this policy change. Li also shows that increased patenting since 2000 is not due to increased R&D. This leaves the Chinese patent boom since 2005 as more likely explained by other policies or economic effects explained earlier in this paper.

Market incentives to innovate

Incentives to patent are not provided exclusively by legal definitions. Competition can also provide an impetus for inventors and firms to innovate, and subsequently patent these innovations. As outlined in the section on economic theory and innovation, endogenous growth theory shows that economic actors have control over the creation of this knowledge. This theory shows that competition increases innovation when firms are near the technology frontier as firms attempt to "escape competition," but decreases it far from the frontier. Market incentives to innovate and patent are industry dependent.

As shown by Du and Chen (2010) and Hu (2010), these market forces exist in China, and may explain a significant amount of the increased patent filings at SIPO per year.

Incentives from patent-promoting policies

Based on systematic analysis of the literature a key driver of the patent explosion appears to be policies enacted by the Chinese government to promote patenting. Patent subsidies, which can amount to tens of thousands of RMB, likely form the single largest patent incentive for inventors.[30]

Subsidies and quotas result in a larger volume of lower-quality patents, as shown by Lei and Sun, et. al. Effects of the Indigenous Innovation policy, which ties government procurement to ownership of Chinese IP, are not fully understood, and will examined in an subsequent paper.

Policy Recommendations

Of the three incentives outlined above (patent definitions, patent promoting policies, and market forces) this paper has shown that patent promoting policies and market forces are likely responsible for increased patenting in China. These incentives have led to a divergence in outcomes- patent volume has increased but suggestive evidence from TFP data points to decreased patent quality. The policies outlined in table 4 could be enacted to promote patent quality:

Table 4: Recommended policy actions and effects to improve patent quality

	Patent volume	**Patent Quality**
Increase market competition	Positive effects – should motivate increased patent volume, particularly in cumulative innovation fields, like the ICT sector.	Positive effects – increased competition should be associated with increased patent quality, as described by Aghion and Howitt.
Strengthen patent enforcement	Positive effects – increased patent enforcement will improve inventors trust in patents, and likely increase their propensity to patent.	Positive effects – increased patent enforcement will improve inventors trust in patents, and likely increase how much information they disclose in patents.
Increased originality thresholds	Negative effects – this would likely reduce the volume of patents, as more patent applications would be rejected.	Positive effects – though patent volume will decrease, increased originality thresholds helps to ensure higher quality patents.

Competition provides significant patent incentives by motivating firms to innovate in order to escape competitors. It also likely motivates higher-quality innovation. Patenting incentives linked to market

[30] For comparison, China's income per capita is approximately $6,000, while patent subsidies can be as high as $4,900. Data from World Bank World Development Indicators.

competition among leading Chinese and foreign firms are more likely to provide incentives to produce higher-quality inventions than other government policies. This is due to the potentially large profits associated with creating truly innovative inventions, which outweighs substantially any government-provided incentives, such as subsidies. These innovations are more likely to be focused in those sectors near the global technology frontier, of which telecommunications and information technology are the closest.

However, the lack of strong enforcement of Chinese patent protection, and low bar for originality deflates the incentives to file patents. This may cause some high-value ideas created through competition to not be patented, or else risk made public and stolen with no recourse for compensation.

Increased originality thresholds are also a key issue in promoting increased patent quality. This has already been addressed as part of the 2009 Patent Law Amendment, which should correlate with decreased patent grant to application ratios as well as decreased invalidity ratios.

Conclusions

Given these incentives, what are the impacts on Chinese technical and economic progress?

The Chinese economy is gradually slowing, with GDP growth down to 7.8 percent in 2012. As shown by Easterly and Levine, knowledge multipliers to the economy, or TFP growth, are an important element of economic growth and drive the majority of cross-country income differences (2001). As shown earlier by Abdih and Joutz (2006) and Ulku (2004), the stock of knowledge, proxied by patents and patent applications, have positive relationships with TFP. However, as Chinese patenting increased, TFP growth decreased, averaging 4.9 percent from 2000 to 2007 and then dropping to 2.3 percent from 2008 to 2011.[31]

Given the positive relationship between TFP growth and patenting and decreasing TFP trends, this casts some doubt on the quality of new innovations developed.

Developing high quality innovation is important to drive TFP by developing the absorptive capacity of Chinese industries. As noted earlier, Eaton and Kortum (1996) empirically show the importance of foreign ideas have over domestic ideas in driving productivity. These empirical findings agree with work by Crafts (2012) that suggests that for many industries and countries diffusion (technical spillovers) are likely more important than invention.

Therefore, the lack of higher quality domestic innovations could impact TFP growth through direct effects and by slowing the dissemination of foreign technology. This impacts both current and future economic development, by limiting absorption of current and potential future foreign technologies. Low quality technology also limits the future technologies developed. This is particularly the case for

[31] TFP data from (January 2013). The Conference Board Total Economy Database. C. Board.

industries that are cumulative innovators, such as the ICT sector. Because of this, increasing the quality of domestic innovation through strengthened patent incentives is increasingly important to stimulate Chinese economic growth.

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Chapter 2: Do Indigenous Innovation Policies Work? Evidence from China

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Abstract: This study analyzes the effect of China's Indigenous Innovation (II) policy on inventiveness, using data on patent applications filed between 2000 and 2011 at the State Intellectual Property Office. It uses two empirical strategies. First, it analyzes data from the PATSTAT patent database using a difference-in-differences approach with count model specifications. Second, it uses firm-level data in a pretest-posttest design to examine the change in patent applications associated with a firm's selection for inclusion under the II policy. The policy did not have positive effects on the targeted technology groups. Firms exhibit increased inventiveness in the year of the award, but rapid declines in subsequent years, with inventive returns accruing to a minor subset of companies. The policy is associated with no detectable increase in inventiveness at the national level, and with only limited firm-level effects which quickly dissipate. These findings suggest that China's Indigenous Innovation interventions may need further refinement. They cast doubt on the effectiveness of "top-down" public procurement policies, which select technologies to be developed by the market, particularly in developing countries.

Glossary

II	**Indigenous Innovation**
IP	**Intellectual Property**
IPC	**International Patent Classification**
OECD	**Organization for Economic Cooperation and Development**
SIPO	**State Intellectual Property Office**
WIPO	**World Intellectual Property Organization**

Introduction

In 2006, the Chinese government implemented a range of "Indigenous Innovation" (hereafter, II) policies aimed at boosting the research and development (R&D) capabilities of domestic high-technology manufacturing industries. The government subsequently incorporated the II concept into government procurement policy, releasing a series of product catalogues identifying domestically produced II-designated products that would receive preference during the government procurement process.

The policy has been highly controversial. Some countries have objected to China's domestic procurement requirements, arguing that they are trade-restrictive, protectionist, and unfairly discriminatory against foreign-invested enterprises (Bason February 29, 2012).

Amid controversy, the national government revoked the national laws linking the II policy with procurement in July 2011. However, provincial and municipal governments continue the II procurement policies (Prud'homme 2013; Lubman July 22 2011). China's cancellation of the national policy suggests that it had diplomatic costs. It is still unclear, however, whether II procurement policies have their intended benefits.

This study evaluates effects on Chinese technological development from the II policy. It uses patent applications filed at China's State Intellectual Property Office (SIPO) as a measure of inventiveness (a proxy for innovation).

The paper addresses two questions: How did the announcement and enactment of the II policy affect innovation in China, particularly in the specific technological areas targeted (telecommunications products, computers, software, office equipment, clean energy devices, and energy efficiency equipment)? And how did selection as a beneficiary of II procurement preferences affect the inventiveness of individual firms?

Patents were sorted by International Patent Classification (IPC) codes and organized by technology class using the World Intellectual Property Organization's (WIPO) technology concordance table. The treatment group was comprised of patents in technology areas targeted under the II policies, whereas the control group contained patents in technology areas that were not targeted.

The study used a standard difference-in-differences design and modeling methods appropriate for analyzing count data. It reports a variety of robustness tests that were used to evaluate the plausibility and robustness of model results, and confirm the structural validity of the research design.

The study is organized into five sections. The Background section details the policy background, and the Literature section reviews the scholarly literature related to public policy, foreign investment, and domestic innovation. The Data section describes the data used, its sources, and its limitations. The Analytical Approach section reports basic descriptive statistics and highlights the trends motivating this research. It also describes the difference-in-differences strategy, reports results, and describes the robustness checks employed. The final section on Results presents key findings, describes their policy implications, and concludes.

My findings should be of interest to policymakers, economists, and other social scientists who are concerned with the interactions between public policy and the innovation process. They should be of particular interest to other developing countries that are considering adopting China's Indigenous Innovation model.

Background

In the late 1990s, the Chinese government established a family of policies to spur innovation among Chinese inventors. Concerned that the Chinese economy was too reliant upon foreign intellectual property, the government pursued policies aimed at spurring the development and commercialization of technology by Chinese firms (US China Business Council 2010). These policies are part of a broader plan for China to move up the value chain by producing more valuable goods and increasing the competitiveness of its businesses.

In support of this goal, and in conjunction with evolving five-year national development plans, the government has instituted a range of policies designed to promote and support domestically produced innovations in science and technology. These include an update of Chinese patent law in October 2009, the amendments of which focused on increasing the threshold of novelty for patents.[32] There has also been a strong focus on industrial and technology-focused policies to promote domestic innovation, referred to as 'Indigenous Innovation' (II) policies (自主创新).

A wide range of policies incorporate the II concept, including those pertaining to the government procurement system. A "Circular on Promoting the Accreditation of New Indigenous Products in 2009," also known as Circular 618,[33] explained that the government would mandate procurement of certain products that were based on intellectual property developed by Chinese firms. The Indigenous Innovation Product Catalog, first promulgated in 2006 and enacted in 2010,[34] listed the products that

[32] For more on the Chinese patent law revisions of 2009 please see: McGregor, J. (2010). "China's drive for 'indigenous innovation': A web of industrial policies." American Chamber of Commerce in China.
[33]For exact rules, please see (2009). Circular of the MOST, NDRC, and MOF on Launching 2009 National Independent Innovation Product Accreditation Work (科技部 国家发展改革委 财政部关于开展 2009 年国家自主创新产品认定工作的通知) MOST Issuance No. 618 Ministry of Science and Technology. Pg 19 National Science and Technology Assessment Center (2009). National Indigenous Innovation Product Reporting Instructions (Year 2009) Ministry of Science and Technology. McGregor, J. (2010). "China's drive for 'indigenous innovation': A web of industrial policies." American Chamber of Commerce in China.
[34] In 2006 plans for the release of the 2009 catalogue were promulgated and included specific product requirements and incentives, however no product catalogue was released at this time. Two separate plans were also released at this time which identified the forthcoming technologies, though not explicitly: The *11th Five Year Plan for Development of the High Tech Industry* and the *2006-2020 Medium to Long Term Science and Technology Plan*, both of which specifically mentioned several of the technologies in the catalogue and the sectors that

that would receive preferential treatment. These rules stated that to qualify for preferential government procurement decisions, a product must be produced by a firm that owned the Chinese intellectual property (IP) through its own research; have associated Intellectual Property (IP) or usage rights owned by a Chinese party, possess a high degree of innovation, have a trademark that is registered in China and owned by a Chinese party, and have a high degree of reliability (National Science and Technology Assessment Center 2009).

Following the 2006 promulgation of the catalog, central, provincial, and municipal government agencies released their own catalogs specifying the products and manufactures that would be given indigenous innovation status and receive preferential treatment in procurement decisions.[35] However the only public information of these was lists of products and their manufacturers that were selected for indigenous innovation status. These listings focused on six product categories: telecommunications products, computers, software, office equipment, clean energy devices, and energy efficient equipment.

The policy underwent several revisions. Following the 2006 catalog and multiple local variants,[36] final rules and a national level catalog were issued in November 2009 for implementation in January 2010. Though a national catalog was never implemented, this policy was enacted in January 2010 accompanied by significant revisions. A major revision only allowed applicants which were manufacturing enterprises that were registered as legal persons in China (Lubman July 22 2011). In April 2010, further revisions were made that required the licensing, rather than ownership, of intellectual property (IP) (Lubman July 22 2011). This policy was later repealed in mid-2011. Though an official catalog was never implemented, many local catalogs were issued following the 2006 promulgation, numbering 74 by January 2011(Lubman July 22 2011).

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produce them, among other technologies and sectors. There were several other policies providing tax breaks to companies using licensed technologies, but no other policies that were technology-focused. For more information please see: (2006). The National Medium- and Long-Term Program for Science and Technology Development (2006-2020). Beijing, The State Council of The People's Republic China

[35] This preferential treatment was described by the *China Business Review* as including: a 5-10 percent preference margin if price is the deciding factor, a 4-8 percent increase in technical and price evaluations, and inclusion in a planned government system for initial purchasing of indigenous innovation-accredited products that will support commercialization of these products.For more on this please see (May 1 2010). Domestic Innovation and Procurement. China Business Review, US-China Business Council. Ministry of Science and Technology. (February 26 2007). "National Indigenous Innovation Products Accreditation Work 解读《国家自主创新产品认定管理办法》." from http://www.most.gov.cn/ztzl/cxqygzhy/cxqyhydt/200702/t20070226_41506.htm.

[36] Initial product catalogs were released by Shanghai, Beijing, Wuhan, and Jiangsu province among others. These catalogs also included other technologies, including farm equipment and other non-high tech goods and included only the final companies and products selected for indigenous innovation product status, and not the original candidate product catalogs. Of note, reports indicated that these product catalogs included very few foreign products. Additionally, they also appeared to exclude products from other provinces and municipalities. See: (May 1 2010). Domestic Innovation and Procurement. China Business Review, US-China Business Council.Reports also indicated that national level catalogs were also circulated for revision, however the exact content of these catalogs is unknown. For examples of information on these catalogs see: (April 2 2008). "2008 Chinese product catalog releases indigenous innovation, energy efficiency products (2008 年中国名牌产品目录突出自主创新、节能环保)."

The policy was met with criticism from foreign businesses, which believed it provided benefits only to Chinese firms (Donohue and Garfield June 16 2012).[37] Due to criticism, the national policy was repealed as of July 1, 2011(Shanghai Securities News July 1 2011). However local versions of the policy that tie ownership of indigenous intellectual property with various incentives have continued (Prud'homme 2013). This study assesses the effects of II policies and the Chinese intellectual property ownership requirement in procurement on China's innovative outputs. It explores whether these policies promote local innovation, and what changes are associated with them.

Literature

There is a substantial body of research on the role procurement policies play in inducing innovation. This process is known as public procurement of innovation and includes a typology of policies based upon the procuring organization and the exact role of the policy in spurring innovation.[38] Governments frequently act as lead purchasers of new technologies. Their demand for large quantities of new products creates new markets and attracts private companies. By providing companies with a steady stream of financing, government procurement can help fund risky R&D for unproven systems. It can also support subsequent commercialization of those technologies by allowing firms to achieve economies of scale, improve product effectiveness and reduce costs before distributing them on the open market. Finally, government-sponsored innovation may diffuse through the wider economy by opening the door for a host of spinoff technologies. Most research has also focused on effects of these policies in the European Union (EU).

Aschhoff and Sofka (2009) find that, among the policy tools available to promote innovation, knowledge spillovers from universities and public procurement are the most effective. They note, however, that the two policies have different effects on innovation: All firms can use university research, whereas for small firms located in high unemployment/low growth regions and technological services (information and communication technology services) and distributive industries (real estate, wholesale trade), public procurement is most effective in promoting innovation (Aschhoff and Sofka 2009).

Government procurement also carries risks. Since governments often procure goods for which no private market exists initially, they often have difficulty in determining appropriate prices for their

[37] See the following examples Donohue, T.J. and Garfield, D.C. (June 16 2012), Protectionism is Back. Wall Street Journal at and Dean C. Garfield
http://online.wsj.com/news/articles/SB10001424052702303768104577462780222989286.
[38] For a typology of these policies see: Rolfstam, M. (2012). "Understanding public procurement of innovation: definitions, innovation types and interaction modes." Innovation Types and Interaction Modes (February 26, 2012).

acquisitions. Information asymmetries, politics, and corruption can all distort the procurement process, sometimes leading to situations in which government costs far exceed the product's benefits.[39]

There is a relative scarcity of research evaluating the effects of procurement policies designed to spur innovation. While there are several relevant case studies, few researchers have conducted empirical studies testing the effects of various policies. [40] A study by Aschhoff and Sofka (2009) is the exception. It uses German data from 2000 to 2002 to analyze the extent to which procurement policy motivates innovation and finds that smaller firms in economically distressed regions and technological and distributive service firms were the largest beneficiaries of public procurement policies.

There are numerous studies looking at patenting in China and Chinese policies designed to promote patenting. Zhou and Stembridge describe the rapid increases in patenting by domestic firms over the past decade, and identify policies associated with this growth (2010). Eberhardt and Helmers show that a select minority of Chinese ICT firms file the majority of patents in China (2011). Chinese policies are found to be a major driver of increased patenting. Prud'homme (2012) and McGregor (2010) identify a number of policies that are designed to promote Chinese patenting, including patent quotas and subsidies. Work by Lei, Sun et. al.(2012; 2013) show that these policies encourage a larger volume of lower quality patents.[41]

There are several studies examining the effects of earlier Chinese II policies, some of which find significant effects on innovation, but they tend to be limited in their methodological approaches. Meng (2011) evaluated two indigenous innovation policies—one enacted in 1996 to promote cooperation between private firms, research institutions, and universities; and another enacted in 2002 to promote research conducted in Chinese centers of higher education. Meng found statistically significant increases in yearly measures of four innovative output metrics, including invention patent applications and grants. The sample size was relatively small, however, and the study lacked a control group, so the validity and statistical power of the estimates are unclear. Liu (Unknown) has also performed basic descriptive analyses of patenting behavior by Chinese inventors as part of a larger analysis of II goals. Liu finds rapid increases in technological outputs between 1999 and 2004, but also finds that many Chinese firms have poor innovation capabilities. Liu's study did not seek to isolate the effects of various aspects of II policies.

Data

Description

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[39] Examples of this include the cost overruns and typical underperformance of US programs to develop new technologies for the private sector. See: Cohen, L. R. (1991). The technology pork barrel, Brookings Institution Press.

[40] For case studies of US examples, see ibid.; For European cases see Edquist, C., L. Hommen, et al. (2000). Public technology procurement and innovation, Springer.

[41] Lei, Z., Z. Sun, et al. (2012). "Are Chinese Patent Applications Politically Driven?", Lei, Z., Z. Sun, et al. (2013). "Patent subsidy and patent filing in China."

All data were drawn from the Patent Statistics Database (PATSTAT Database) offered by the European Patent Office. All invention and utility patent applications at SIPO between 1985 and 2012 were extracted from this database. These data are coded into component technologies by International Patent Classification (IPC) code at the 4-digit level.[42] The data are aggregated by first IPC code,[43] application month and year. All applications in the data are priority applications.[44]

Dependent Variables

The dependent variables used in this study are patent application counts aggregated by IPC four digit class. Patents were used as a measure of inventiveness in a particular technological area. Using patent data in this manner follows a longstanding precedent in the literature, and numerous studies have confirmed its validity (Zuniga, Guellec et al. 2009). While some studies recommend using multiple innovation metrics, such as patents, R&D expenditures, and trademarks (OECD 2002) others find that the overlap between these measures is so large that any may be used individually with a high degree of reliability to capture innovative firm performance (Hagedoorn and Cloodt 2003).[45]

Independent Variables

The independent variables used in this study are all indicator variables that represent treatment status and year. Selection of treatment and control groups is based upon products listed in the ***2009 National Indigenous Innovation Product and Technology Fields Catalogue*** (*2009 年国家自主创新产品认定技术领域*) issued by the Chinese government. Translating these product groups into IPC codes was accomplished using the World Intellectual Property Organization (WIPO) technology concordance

[42] The IPC is a hierarchical technological classification system. Every patent grant is assigned at least one IPC code, and IPC codes are divided into classes and subclasses. Classes are divided among the technologies utilized (e.g. electricity, physics, textiles, etc.) and a code for a specific technology. For example D01 is the code for natural or artificial threads or fibers; D01B is the subclass code for mechanical treatment of natural fibrous or filamentary materials; D01B 1/02 is the four digit code for separating vegetable fibers from seeds, e.g. cotton. For a full listing of IPC codes, please see World Intellectual Property Organization (2013). International Patent Classification (IPC) Official Publication.

[43] Since patent applications are typically provided with multiple IPC codes, there is also a first code that is assigned to each application. The data included in this study is limited to only the first codes to better discern the primary coding of each patent application.

[44] A priority application is an original patent application, that is, it is not a reapplication of an earlier patent.

[45] Hagedoorn and Cloodt examine four innovative performance measures: new product announcements, number of patents filed by a firm, R&D inputs, and patent citations, and find that the "statistical overlap" among these is so high that any individual metric could also be used to measure innovative performance. See Hagedoorn, J. and M. Cloodt (2003). "Measuring innovative performance: is there an advantage in using multiple indicators?" Research Policy **32**(8): 1365-1379.

tables.[46] The tables listing the "treated" technologies and their IPC codes are listed in the appendix of this paper.

The treatment group is comprised of patents with IPC codes associated with technologies affected by the II policy. An exact listing of these codes is provided in the appendix.

The control group is drawn from patents associated with technologies not included in the II catalogs. Control technologies were chosen from the same supra categories, e.g. Electricity (H) and Physics (G), as the treatment technologies.[47] This was done to ensure that technologies in the control and treatment groups were similar in terms of the level of knowledge and capital intensity required to research and develop them. This reduced the extent to which differences in performance across the two groups could be attributed to the heterogeneous effects of exogenous factors.

Specific IPC codes for the control group were selected based upon correlation with IPC codes in the treatment group. A correlation table of patent counts by IPC class from 1985-2005 for all treated classes and potential control classes was created. Each IPC class in the treatment group was then paired with an IPC class in the control group with the highest correlation of pre-treatment growth trends. Summary statistics of these correlations are displayed in table 1.

Table 1: Treatment-control pairings correlation statistics

Average Correlation	.976
Median Correlation	1
Standard Deviation	.065
Total IPC Classes in Treatment/Control Groups	263 treatment/263 control

To evaluate the effect on innovation of the 2006 announcement of a shift towards an II model—which likely acted as a signal to the market—I compared patenting patterns during the six years prior to the announcement to those during the four years following the announcement. I measured the effect of the full-scale implementation of II procurement policy and the release of the November 2009 catalog by comparing patenting during the six years prior to the announcement (2000-2006), to patenting in the two years post-catalogue (2010-2011). I also focused in on a shorter period, and compared patenting in the six months prior to (July 2009-December 2009) and following policy implementation (January 2010-June 2010).

[46] World Intellectual Property Organization (January 2013). IPC - Technology Concordance Table. I.-T. C. Table.xls, World Intellectual Property Organization.
[47] H and G are the supra-classification codes used in the IPC coding schema for electricity and physics, respectively.

Summary statistics

Table 2 below provides an overview of the data used in this analysis. As described earlier, IPC codes were restricted to the first classified IPC code and the data below are divided into treatment and control groups. Patent count data were aggregated from the PATSTAT database. This database includes all bibliographic data from approximately 3 million patent applications filed at SIPO.[48] Bibliographic information used in this study included application date and associated IPC codes at the 4-digit level. Counts were then assembled for each IPC class by year.

Table 2: Patent dataset summary statistics

	Total	**Treatment**	**Control**
Total number of patent count-year observations	14728	7364	7364
Number of IPC groups	526	263	263
Mean number of patents per IPC group per year	35.13	42.15	28.10
Standard deviation	188.27	227.14	138.57

As shown in Table 2, there were a total of 526 IPC groups used in this study, divided equally between treatment and control groups. For the treatment groups in this study, average patent counts and standard deviations were larger than those in the control groups.

Analytical Approach

Empirical Strategy

I used two different methods to examine the effects of II procurement policy: a difference-in-differences strategy, and an analysis of firm patent counts. First, I employed a difference-in-differences approach to evaluate the effects of the policy on a national level.

[48] This includes application date, inventor information, application information, patent title and abstract, as well as all publication data, among many others. For a full list of fields included in the PATSTAT database see: (October 2013). Data Catalog PATSTAT - EPO Worldwide Patent Statistical Database, European Patent Office.

Difference-in-differences design

The II procurement policy only affected targeted products associated with certain technology groups. The difference-in-differences strategy allowed for comparison between patenting activity in targeted technology groups and those in non-targeted groups. The resulting control and treatment groups were composed of eligible patents that are very similar in terms of observed characteristics, and therefore also likely in terms of unobserved characteristics. Patent classes in the treatment group were assigned matches in the control group that are similar in terms of their technological content. Patent classes in the treatment and control groups were also chosen based on having similar pre-intervention growth trends. Although patent classes in the control group do differ in terms of their overall level of patenting, the similarities between the trends and technological features in each group should be sufficient to control for the effects of non-treatment exogenous factors. Since the control group closely matches the treatment group, analysis of differences between the two post-implementation of the II policy should provide an accurate estimate of the policy's causal effects.

A natural candidate for the analysis of patent data is the Poisson model, since the number of patents in each technology class in a certain period is nonnegative and has a positively skewed distribution. However, there is a large number of zero's in this data which causes the variance of the count to not equal its mean, or a case of "over-dispersion." The negative binomial model is an appropriate alternative. The Tobit model is another appropriate alternative. The three modeling approaches are frequently used in the literature on patents, given the structure of the data. I also estimated a fixed effects model to control for technology-specific heterogeneous effects that could confound estimation.[49]

Prior research has found that the Poisson family of models used with Chinese patent data produces valid estimates (Hu and Jefferson 2009). Tobit models have also been widely used to examine patent count data (Crepon, Duguet et al. 1998; Maurseth and Verspagen 2002; Payne and Siow 2003). Although the negative binomial specification is more appropriate in some respects due to the over-dispersion of the data, prior studies have found that the approach has several limitations and is only valid if the data satisfy specific assumptions (Guimaraes 2008). The need to control for heterogeneity among IPC classes poses additional complications. Hausman, Hall and Griliches (1984) constructed an estimator that functioned as a negative binomial with fixed effects. However subsequently Allison and Waterman (2002) concluded that this model allows for individual variation to impact the dispersion parameter which produces incorrect parameter estimates, particularly when covariates are time-invariant.[50] Another option to deal with over-dispersion is the Poisson Quasi-Maximum Likelihood method, used by Hu and Jefferson in their analysis of Chinese patenting. This method can be estimated using the normal Poisson model and substituting robust standard errors in place of the standard errors (Cameron and Trivedi 2005). The Poisson Quasi-Maximum Likelihood method was also used to estimate this model with identical results to those shown later in this paper, and are available upon request. Although I

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[49] Examples of these fixed effects could include unobservable across-technology differences that affect patenting. This could include popularity of patenting in certain technology classes, or larger recognition or profits from patenting in certain technologies.

[50] For further discussion see Allison, P. D. and R. P. Waterman (2002). "Fixed–effects negative binomial regression models." Sociological methodology **32**(1): 247-265.

primarily focus on the results of the Poisson model, I also report the results of negative binomial and Tobit models, which served as robustness checks and confirmed my findings.

The general model is a standard two-period difference-in-differences model with the following specification:

$$Y_{cgt} = B_0 + B_1 X_g + B_2 T_t + \theta X_g \cdot T_t + \varepsilon_{cgt}$$

The dependent variable, Y_{cgt}, is patent application counts in patent class *c* in technology group *g* in year *t*. I examined both normal and log-transformed patent counts. Dummy variables for the treatment and pre/post treatment status were included in the regression, represented by X_g and T_t, respectively. An interaction term, $X_g \cdot T_t$ represents the treatment effect in the post period that is the subject of this study. The coefficient of the interaction term θ is the primary variable of interest. Dummy variables equal one for observations in the treatment group (X_g), or one if observations fall in the post intervention period (T_t). This treatment effect estimate can be calculated by:

$$\theta = (\bar{y}_{T,2} - \bar{y}_{T,1}) - (\bar{y}_{C,2} - \bar{y}_{C,1})$$

Applied to the Poisson probability model this can be specified as the following:

$$f(y_{igt}|\lambda_{igt}) = \frac{\exp(-\lambda_{igt})\lambda_{igt}^{y_{igt}}}{y_{igt}!}$$

Where:

$$\lambda_{igt} = E(y_{igt}|\lambda_{igt}) = \exp(B_0 + B_1 X_{gt} + B_2 T_t + \theta X_{gt} \cdot T_t)$$

Model parameters were then estimated using normal maximum likelihood methods. Treatment effects were calculated at the IPC class level. For the fixed effects model used in this study, a dummy for each technology group was also included.

Firm-level analysis

I also analyzed the policy's effect on the specific firms that were selected in either provincial or municipal II catalogs. Pre/post calculations were performed on the one, two, and three year averages of patent applications and year-on-year changes in patent applications before and after inclusion in these catalogs. Where the treatment effect for firm *i* was calculated using the following:

$$Treatment\ effect_i = Y_{it} - Y_{it-1}$$

Where Y indicates the number of patent applications and t is the post period and t-1 the pre period. Due to the highly opaque nature of the awards process, selection of a control group from firms that unsuccessfully applied for II status was not possible. Firms were included if their selected product was in information technology, computer equipment, or audiovisual technology and if their company name matched with the firm name listed in the II catalogs and those listed in the EEE-PPAT harmonized patent name database.[51] Due to the nature of patenting from multiple subsidiaries, analysis was executed on those firms that have exact name matches with the II catalogs.[52] Firms were drawn from the following catalogs:

- 2007: Beijing; Jiangsu
- 2008: Jiangsu; Hebei
- 2009: Beijing; Shanghai; Jiangsu; Wuhan; Guangzhou; Guangdong

Table 3: Firm data descriptive statistics 2000-2011

	Number of firms	Total number of patent applications	Median patent applications per firm	Mean patent applications per firm	Standard Deviation
Total	45*	4195	8	91.7	237.67
2007 Cohort	12	2550	24.5	196.15	399.64
2008 Cohort	5	475	6	27.2	171.34
2009 Cohort	29	1623	10	55.96	111.75

*Notes: One firm, Panda Electronics, was awarded II status in both 2007 and 2008 and is counted in each of these cohorts.

Descriptive Evidence

[51] The ECOOM-EUROSTAT-EPO PATSTAT Person Augmented Table (EEE-PPAT) harmonizes names of inventors and applicants in the PATSTAT database to account for misspellings, and variants of company names which frequently reflect subsidiary R&D operations. For more on this please see (2013). "EEE-PPAT." from http://www.ecoom.be/en/EEE-PPAT.

[52] If firms in the patent database had minor naming differences (i.e. Nanjing Linkage Technology Company/Nanjing Linkage Technology Group Company) and one of the names was an exact match to the firm name listed in the II catalog, their patent counts were aggregated to create a parent company. Examples of this include Founder Technologies and Beijing Vimicro Corporation. Of note, subsidiaries of both ZTE and Huawei, two of the most prolific patenting Chinese organizations were included in local II catalogs. However because there was not an exact name match between for firm names in the patent database, they were not included in this dataset.

These firms were also not included because of the regional nature of these catalogs and the inability to attribute local incentives in one province to firm patenting behavior in other provinces. As noted by other researchers, the II policy is designed to support firms in a municipality or province. Both of these firms have extensive operations throughout China, and local incentives that apply to the operations of these firms in one location may not apply to operations in other locations. This also includes these firms' operations with joint venture partners throughout China, of which both firms have several.

The promulgation of the II policy in 2006 and its enactment in late 2009 coincided with an increase in patenting across several technology classes. Chart one illustrates a striking trend- there was a rapid increase in patents granted to Chinese inventors from 2007-2010, with a spike of patents in 2009 among the H supra-class (electricity related patents) and G supra-class (physics-related patents) patents, the two classes most likely to be impacted by this policy. Further examination of patents granted by SIPO to domestic and foreign firms showed a slightly smaller effect among G and H patents filed by domestic Chinese firms during this same time period. This suggests that the II policy is not responsible for the increase in patenting.

Figure 1: Physics (G) and Electricity (H) class SIPO domestic and foreign patent grants

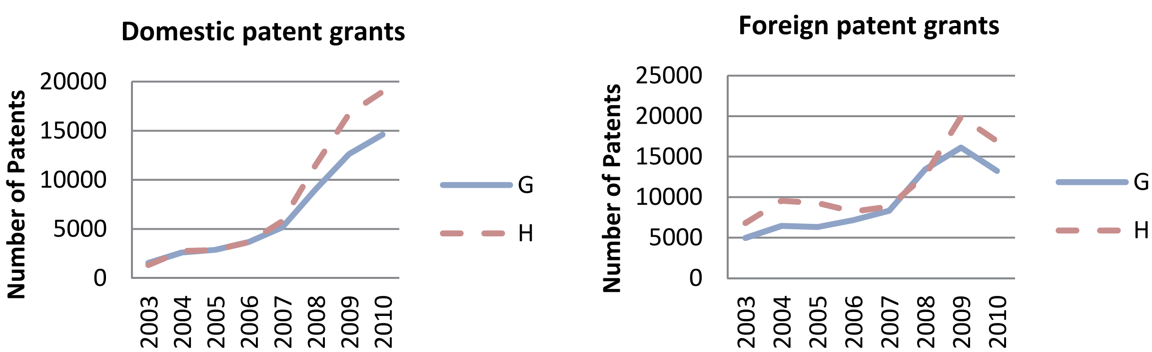


Figure 2: Yearly means of treatment and control groups

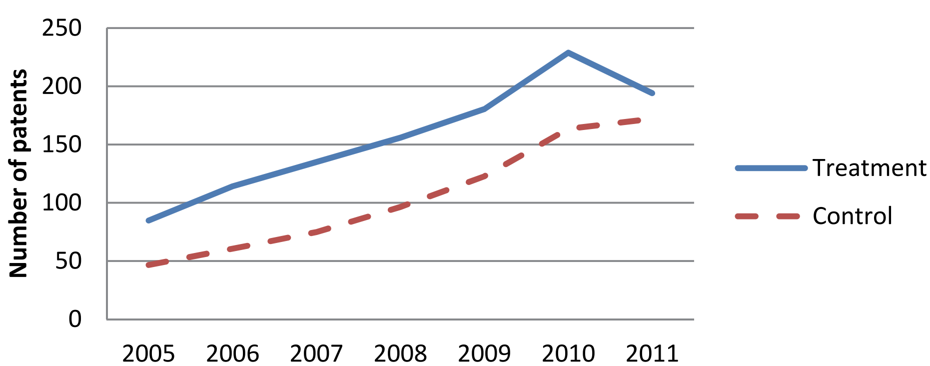
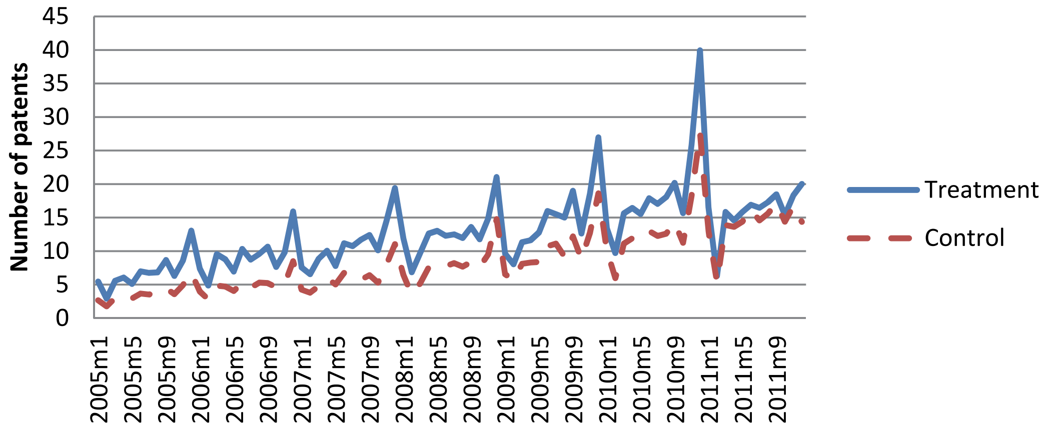


Figure 3: Monthly means of treatment and control groups



Figures 2 and 3 show the yearly and monthly averages of the treatment and control groups between 2005 and 2011. Figure 2 above shows a striking trend among treated patent applications- there was a rapid increase in patent applications from 2007-2010, and a spike of patents in 2010. Further examination of these patent applications by month shows a similar overall trend. There are significant yearly cycles, with the majority of patent applications filed at the end of the year, likely due to yearly patent quotas issued by local and municipal governments.[53] Figure 3 shows that patenting in the treatment and control groups track each other closely and possibly converge after the II policy, rather than diverge.

Results

Results from the Difference-in-Differences Study Design

Analysis began by using the methods described in the empirical strategy discussed earlier in this paper, and are shown in table 3. Given the panel data used in this paper and the need to control for fixed effects, a Poisson model with fixed effects clustered at the IPC group level was used as the primary model, with the Negative Binomial and Tobit models for robustness checks. Table 3 presents the results of analyses of patent count data aggregated by year.

[53] For more on Chinese patent quotas please see:Prud'homme, D. (2012). Dulling the Cutting Edge: How Patent-Related Policies and Practices Hamper Innovation in China, University Library of Munich, Germany.

Table 3: Interaction coefficient results by data source and method

Panel 1: Testing the market signal
Pre:2000-2005/Post:2006-2009

	Regular data				Logged data			
Variable\Model	**Poisson**	**Poisson RE**	**Poisson FE**	**Poisson FE w/ clustering**	**Poisson**	**Poisson RE**	**Poisson FE**	**Poisson FE w/ clustering**
Treatment	0.661***	0.661***			0.315***	0.315***		
	(0.137)	(0.137)			(0.0775)	(0.0775)		
Post	1.886***	1.886***	1.886***	1.886***	1.190***	1.190***	1.190***	1.190***
	(0.00761)	(0.00761)	(0.00761)	(0.0699)	(0.0319)	(0.0319)	(0.0319)	(0.0358)
Interaction	-0.159***	-0.159***	-0.159***	-0.159*	-0.272***	-0.272***	-0.272***	-0.272***
	(0.00942)	(0.00942)	(0.00942)	(0.0839)	(0.0429)	(0.0429)	(0.0429)	(0.0489)
Constant	2.599***	2.599***			-0.100*	-0.100*		
	(0.0967)	(0.0967)			(0.0556)	(0.0556)		
# obs	5,260	5,260	5,260	5,260	5,260	5,260	5,140	5,140
# groups	526	526	526	526	526	526	514	514
Log likelihood	-72983	-72983	-69328	-69328	-7808	-7808	-5756	-5756

*** p<0.01, ** p<0.05, * p<0.1

Panel 2: Time-lagged effects from the market signal
Pre:2000-2005/Post:2010-2011

	Regular data				Logged data			
Variable\Model	**Poisson**	**Poisson RE**	**Poisson FE**	**Poisson FE w/ clustering**	**Poisson**	**Poisson RE**	**Poisson FE**	**Poisson FE w/ clustering**
Treatment	0.661***	0.661***			0.315***	0.315***		
	(0.140)	(0.140)			(0.0791)	(0.0791)		
Post	2.524***	2.524***	2.524***	2.524***	1.354***	1.354***	1.354***	1.354***
	(0.00765)	(0.00765)	(0.00765)	(0.105)	(0.0353)	(0.0353)	(0.0353)	(0.0413)
Interaction	-0.430***	-0.430***	-0.430***	-0.430***	-0.353***	-0.353***	-0.353***	-0.353***
	(0.00958)	(0.00958)	(0.00958)	(0.139)	(0.0482)	(0.0482)	(0.0482)	(0.0564)
Constant	2.599***	2.599***			-0.100*	-0.100*		
	(0.0991)	(0.0991)			(0.0568)	(0.0568)		
Number of Observations	4,208	4,208	4,208	4,208	4,208	4,208	3,976	3,976
Number of Groups	526	526	526	526	526	526	497	497
Log likelihood	-65145	-65145	-61593	-61593	-6266	-6266	-4377	-4377

*** p<0.01, ** p<0.05, * p<0.1

Panel 3: Effects from policy implementation
Pre:2007-2009/Post:2010-2011

	Regular data				Logged data			
Variable\Model	**Poisson**	**Poisson RE**	**Poisson FE**	**Poisson FE w/ clustering**	**Poisson**	**Poisson RE**	**Poisson FE**	**Poisson FE w/ clustering**
Treatment	0.472***	0.472***			0.0332	0.0332		
	(0.142)	(0.142)			(0.0674)	(0.0674)		
Post	0.538***	0.538***	0.538***	0.527***	0.127***	0.127***	0.127***	0.127***
	(0.00493)	(0.00493)	(0.00493)	(0.0451)	(0.0309)	(0.0309)	(0.0309)	(0.0115)
Interaction	-0.241***	-0.241***	-0.241***	-0.216***	-0.0719	-0.0719	-0.0719	-0.0719***
	(0.00643)	(0.00643)	(0.00643)	(0.0774)	(0.0438)	(0.0438)	(0.0438)	(0.0169)
Constant	4.585***	4.585***			1.127***	1.127***		
	(0.1)	(0.1)			(0.0478)	(0.0478)		
Obs	2,630	2,630	2,590	2,590	2,630	2,630	2,535	2,535
# groups	526	526	518	518	526	526	507	507
Log likelihood	-26764	-26764	-23004	-23004	-4661	-4661	-2696	-2696

*** p<0.01, ** p<0.05, * p<0.1

Table 3 reports the coefficients obtained in the three difference-in-differences models estimated in three separate panels. Panel 1 reports the results of the model used to examine whether policy changes in 2006 served as a 'market signal' influencing inventiveness. The events of interest are the release of the II policy accreditation rules and two policy documents: the *11th Five Year Plan for Development of the High Tech Industry* and the *2006-2020 Medium to Long Term Science and Technology Plan*. Panel 2 displays estimates of the time lagged effects of the 2006 'market signal' on policy implementation in 2010. Finally panel 3 shows the effects of policy implementation in 2010. In each case, the coefficient of interest, the difference-in-differences estimate, is the coefficient on the interaction term $X_{gt} \cdot T_t$.

Before discussing the results of the interaction term I will review the effects of the time and treatment coefficients. Turning first to the time coefficients, across all three panels we see a positive effect. That is, the later time periods are associated with higher levels of patent applications, which fits with overall trends reviewed at the beginning of this section and the first paper of this dissertation. Treatment group effects are also positive, but with significantly lower magnitude. This also fits with established trends, as patenting in ICT technologies at SIPO has grown rapidly in comparison to other technologies. It also may suggest selection bias in the Indigenous Innovation catalog: drafters of this policy may have selected the highest performing technology classes for inclusion.

All coefficients of interest in Panel 1 (those associated with the interaction terms) are negative, small in magnitude, and statistically significant. After the market signal, patent applications in treated technologies were associated with .85 times as many patent applications as control technologies. This policy is associated with a decrease in the likelihood of patent applications. This suggests a spurious relationship between patent counts and the II policy.

Impacts of the 2006 market signal on 2010 and 2011 data, shown in panel 2, were also examined to understand if any time-lagged effects exist. Again all coefficients were slightly negative and statistically significant. These results show that the 2006 market signal had no positive effects in 2010 or 2011.

Next the effects of the November 2009 announcement on patent applications in the 2010 and 2011 were examined, labelled as 2010 pre/post in table 3. As with the results for the 2006 market signal, coefficients are all negative and small in magnitude. These findings are interpreted as a lack of effects from the November 2009 policy in the following years.

Next the November 2009 national announcement was examined using monthly data. Examining a six month pre-post period in table 4 we can see similar results to those shown in table 3.

Table 4: November 2009 pre/post difference-in differences results using monthly data (Pre: May 2009-October 2009/Post: November 2009-April 2010)

	Regular data				**Logged data**			
	Poisson	**Poisson RE**	**Poisson FE**	**Poisson FE w/ clustering**	**Poisson**	**Poisson RE**	**Poisson FE**	**Poisson FE w/ clustering**
Treatment	0.400***	0.400***			0.117	0.117		
	(0.147)	(0.147)			(0.081)	(0.081)		
Post	0.070***	0.070***	0.070***	0.070***	0.022	0.022	0.17	0.17
	(0.010)	(0.010)	(0.010)	(0.010)	(0.031)	(0.031)	(0.31)	(0.138)
Interaction	-0.059***	-0.059***	-0.059***	-0.059***	-0.0307	-0.0307	-0.027	-0.027
	(0.0138)	(0.0138)	(0.0138)	(0.0138)	(0.044)	(0.044)	(0.043)	(0.018)
Constant	2.379***	2.379***			0.390***	0.390***		
	(0.104)	(0.104)			(0.057)	(0.057)		
Obs	6,312	6,312	6,312	6,312	4,394	4,394	4,257	4,257
# groups	526	526	526	526	494	494	428	428
Log likelihood	-17391	-17391	-14453	-14453	-6214	-6214	-4506	-2696

*** p<0.01, ** p<0.05, * p<0.1

Results follow the trends described earlier, with slightly negative results across all models. These slightly negative results can be interpreted as a lack of a causal relationship between the II policy and increased patenting. There is no evidence from econometric results to show that patent applications increased following the announcement in November 2009 in either the months or years data.

Robustness checks

Robustness checks were performed using two different methods. Tobit and negative binomial models were used to confirm the results of the Poisson results. Additionally, a difference-in-differences approach was run on earlier years to confirm the suitability of the method.

Table 4: Robustness checks: Interaction coefficient results by data source and method

	Market signal Pre:2000-2005/Post:2006-2009		Market signal lagged effects Pre:2000-2005/Post:2010-2011		Implementation Effects Pre:2007-2009/Post:2010-2011	
	Regular data	**Logged data**	**Regular data**	**Logged data**	**Regular data**	**Logged data**
Negative Binomial	-0.329***	No results	-0.568***	-0.385***	-0.251***	No results
	(0.0567)		(0.0664)	(0.0543)	(0.0374)	
Negative Binomial with RE	-0.329***	No results	-0.568***	-0.385***	-0.251***	No results
	(0.0567)		(0.0664)	(0.0543)	(0.0374)	
Tobit	17.01	-0.574***	-2.152	-0.885***	-13.49	-0.251
	(15.57)	(0.153)	(22.88)	(0.208)	(33.48)	(0.184)

*** p<0.01, ** p<0.05, * p<0.1

November 2009 monthly effects
(Pre: May 2009-October 2009/Post: November 2009-April 2010)

	November 2009 data	**Logged November 2009 data**
Negative Binomial	-0.0497	No results
	(0.031)	
Negative Binomial with RE	-0.0497	No results
	(0.031)	
Tobit	-0.515	-0.056
	(2.407)	(0.101)

*** p<0.01, ** p<0.05, * p<0.1

As shown previously in this paper, negative binomial results closely matched the Poisson results. The results above show the coefficients are negative and significant for nearly all of sets of data, with the exception being the Tobit model with the 2006 data. However, the Tobit model's positive coefficient with the 2006 data disappears when the dependent variable is logged. This latter result is the more robust of the two Tobit findings, as the logged data better approximates a censored normal distribution, a key assumption for the Tobit model. The exception to these results is the negative binomial models, which did not return results due to hitting a discontinuous region when attempting estimation. This may be due to the short time span evaluated, which limited data available for this estimate.

Table 5: Falsification test: Difference-in-differences estimate by data source and method

	Poisson	**Negative Binomial**	**Tobit (with logged data)**
2003 data	-0.388***	-0.375***	-0.760***
	(0.0352)	(0.104)	(0.227)

A difference in difference model was also run on earlier data (a falsification test) to determine if pre-existing trends were present. Using 2003 as the initiation of the hypothetical treatment, the difference in difference model used three years pre/post to analyze for treatment effects. This model found similar results to the primary findings earlier in this paper.

The falsification test shows that this analysis detects a pre-existing trend in the data rather than a causal effect. This analysis indicates that relationship between this policy and the targeted technology groups is more likely a spurious relationship, rather than causal.

Results from the Pre-Post Study Design

Given the non-uniform initiation of the II policy, an investigation of firm-level data and local II catalogs from 2007 to 2009 allows for a better understanding of the policy's effects. These data yield similar trends to those previously described. Three cohorts of II awardees (2007, 2008, and 2009 awardees) were examined to determine whether, and how, their inventiveness responded. Examining average awardee patent applications by cohort yields trends that show an uptick in patent applications in the year following their awards. Examining the average year on year changes in patent applications by cohort we see similar trends: rapid drops in patenting in years subsequent to awards. The 2007 cohort showed positive effects in 2008, and then a rapid decrease in following years. 2008 awardees showed no improvement in the year of the award, and had a similar decrease in patent applications in following years. The 2009 awardees, the largest group among the three examined, showed a slight increase in 2009, and then exhibited a decrease in patent applications the following year.

Figure 4: Average awardee patent applications by cohort

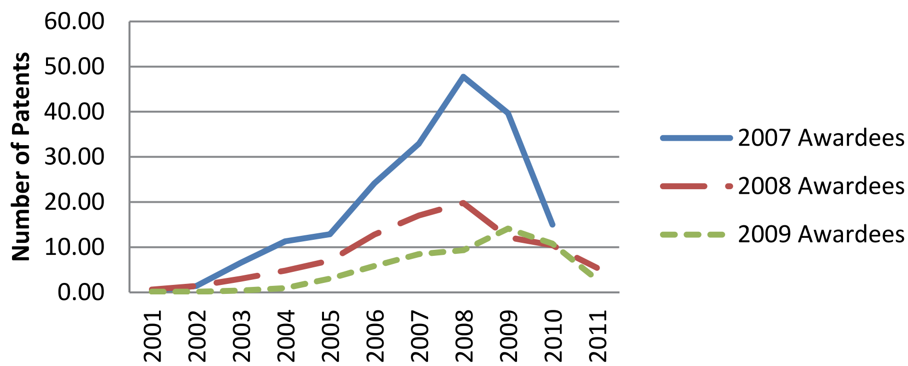


Figure 5: Average year-on-year changes in awardee patent applications by cohort

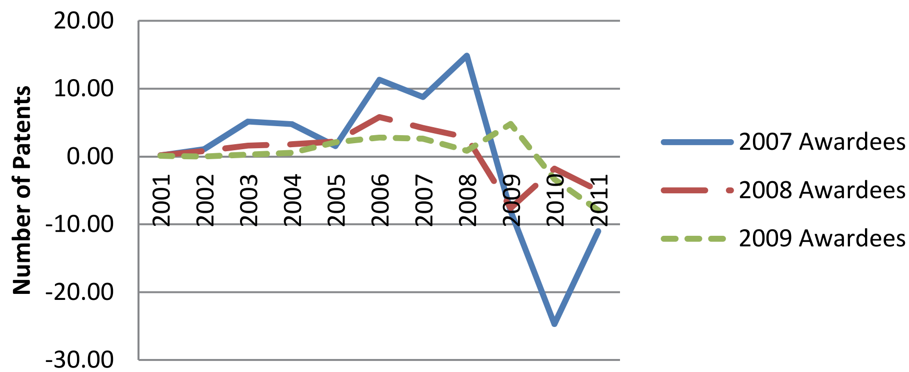
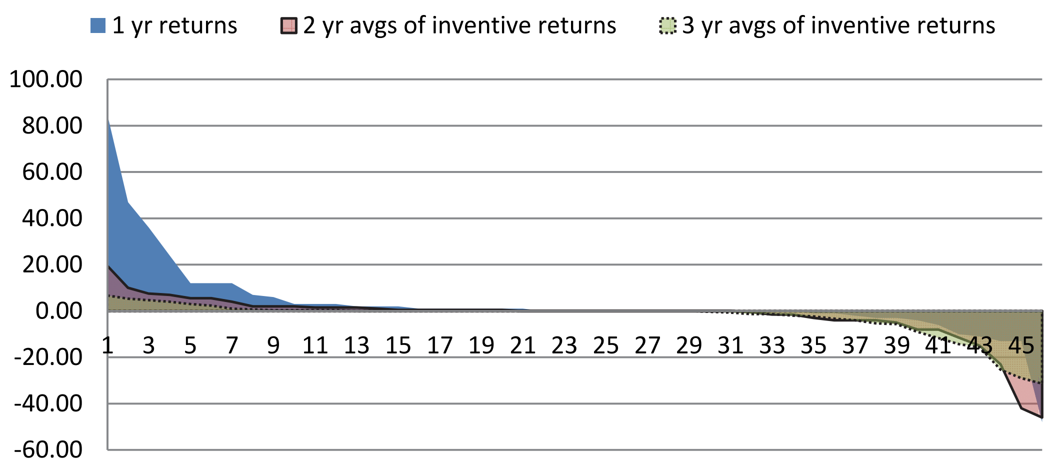


Figure 6: Distribution of Inventive Returns to II policy



Note: each X axis point represents one firm

However, as shown in the descriptive statistics for this data, patenting varies greatly by firm, with a small share of firms exhibiting larger annual increases in patenting activity. In the distribution of one- and two-year inventive returns[54] by firms selected under the II policy, two long tails are apparent: a small number of firms that have large increases in inventiveness, and a small number of firms that have large decreases in inventiveness. Examining the one year returns in chart 6, we can see that two firms account for nearly all inventive returns for this time span, or 132 of 147 net patent applications. This long 'right tail' contributes to the aggregate performance of cohorts, but belies weaker patenting trends among the majority of firms. The two- and three-year average of inventive returns shows a similar trend, but with a larger population of firms with negative returns. Aggregating the performance of these firms, there was a net positive inventiveness return over one year, but a net decrease in inventiveness over two and three years.

Table 6: II policy returns

	Net returns	**Average**	**Median**	**Std dev.**
1 yr	147	3.2	0	17.65
2 yr average	-103.5	-2.25	0	10.86
3 yr average	-133.67	-2.91	0	8.04

Notes: An inventive return is the difference between the average change in patenting of a firm in the pre-II and post-II periods. For example, the 2 year average returns are the difference between the two year average change in patenting of a firm before and after gaining II status. The net return is the difference in the sum of these for all 45 firms.

The three year pre/post averages of year-on-year changes in patent applications exhibit a similar trend: very few firms have inventive returns more than one year after their selection. Of the 45 firms in this dataset, nine showed improvements in patenting following their awards over a three year period. Among these firms, the median average improvement in patenting over three years was 2.33 patent applications per year, with the best performing firm averaging a 6.7 patent improvement per year.

The firm level analysis raises further questions regarding the effectiveness of II procurement policies. Were the policy effective in boosting a firm's investments in research and development, we might expect to see positive effects for an extended period following firms' selection for II status. The year-on-year effects by cohort exhibit no clear pattern. Some cohorts have initial increases in inventiveness and then later decreases. Others show no increases since their awards. The largest of the cohorts, the 2009 cohort with 29 firms, shows a decrease in inventiveness following awards in 2009. Year on year changes are more revealing, and show short-lived increases in net inventiveness in the year of the award that are quickly erased in subsequent years. This one-year return is attributable to less than half the firms examined, and nearly all returns are from only two firms, both of which had significant decreases in patenting in subsequent years. The one-year returns in inventiveness could also indicate that these firms are patenting strategically and do not accrue any characteristics that lead to longer-term inventive output. Lei, et al. (2013) find that subsidies lead firms to act strategically by distributing patent claims

[54] Inventive returns are calculated by subtracting the pre period from the post period. For example the 2 year average inventive return is calculated by subtracting the 2 year average of patent applications prior to II status from the 2 year average of patent applications following II status.

among larger numbers of patents to increase total patent applications.[55] Firms' responses to the II policy may be similar. Firms in this study appear to increase inventiveness when they receive II status and then reduce inventiveness in subsequent years.

There is also evidence of two other trends. Regardless of the year of an award, there is a uniform decrease in patent applications in 2010 and 2011 among the firms examined. Finally, all cohorts achieve similar levels of patenting in 2011. This could be due to exogenous factors that overcame any policy effects.[56]

Firm-level analysis confirms the difference-in-differences findings. The lack of uniform improvements in patenting over multiple years indicates that this policy was ineffective in promoting innovation among these firms. The firm level analysis also confirms the findings of Eberhardt and Helmers (2011), who identified that the majority of Chinese patents come from a minority of export-oriented and young firms.[57]

Contribution and limitations

My analysis suggests that the II policies had no economically significant effects on inventiveness in the technology groups targeted. My research challenges the findings of previous studies on public procurement for innovation policies, including work by Aschhoff and Sofka (2009)and Meng. Aschhoff and Sofka find that public procurement for innovation is highly effective in motivating innovation, particularly among small technology service firms. My study differs from theirs in several important aspects. Their work focuses on economic outcomes of all public procurement (including defense), whereas my study focuses on technical outcomes in the civilian market. Because of the technology focus of this study, firm-size aspects of these policies are undetectable. Finally, these authors use data from Germany, a developed and highly innovative country with mature institutions. Chinese institutions, as well as research and development capabilities, are not as advanced, and this study evaluates policy effects of public procurement for innovation in a developing country.

The findings in this study also differ from the findings by Meng (2011) in his evaluation of the 1996 and 2002 iterations of the II policy. Meng found large effects from these policies; however his research was limited in two key aspects: it focused on a small sample of Chinese universities and lacked a control group. My study uses a larger sample of firms and controls for exogenous effects by comparing targeted technology groups with non-targeted groups. Differences in findings could also be attributable to the short time span (2010-2011) the II policy was in place.

My research adds to the literature addressing public procurement for innovation policies and addresses several gaps. First, it attempts to evaluate the efficacy of public procurement for innovation policies

[55] Lei, Z., Z. Sun, et al. (2013). "Patent subsidy and patent filing in China."
[56] Examples of exogenous effects includes increased costs of R&D, or changes in macroeconomic conditions.
[57] Eberhardt, M. and C. Helmers (2011). Is the Dragon Learning to Fly? An Analysis of the Chinese Patent Explosion.

with empirical evidence. Examples of innovative procurement outside of the EU are lacking in the current literature. Additionally the majority of prior evaluations have not attempted to evaluate treatment effects of such policies using technological outcomes.

This research also contributes to the debate about the viability of overall “top-down” public procurement innovation strategies for nations. The lack of positive effects from the market signal since 2006 and implementation in 2010 have significant implications for public procurement policies designed to stimulate innovation in developing nations. Selection of technologies for public procurement may not be as effective as fostering innovation through creating a favorable economic and institutional environment.

This research also provides suggestive evidence of the contribution of strengthened IPR on inventiveness. The spikes in patent applications in 2009 among both the treatment and control groups are likely explained by changes in China’s patent law. In October 2009 higher standards or novelty were implemented in China’s patent system, effectively changing the threshold for prior art from “known in China” to an “absolute novelty” standard that is employed throughout the world. This increase in originality thresholds could also be a confounding source of increasing patenting rates. Such a policy would likely have broad effects on patenting across all classes, as inventors would look to protect their inventions.

This research is subject to certain data limitations. The largest limitation is the short timeframe for which data were available; only aggregate statistics to 2011 were available. Ideally data to 2013 would be available to better evaluate post treatment effects. Conversely, the short lifespan of this policy could affect the innovative outputs associated with it.

The methodological approach also has some limitations. A risk of difference-in-differences research designs is that the intervention could be falsely attributed as the cause of any treatment effects (differences between treatment and control groups). Although I took several steps to ensure that the treatment and control groups were similar, the “treatment” was not perfectly randomly assigned, so there is a prospect of selection bias. The technologies targeted under China’s II policy may differ in ways related to their prospects for patent growth.

There are also China-specific factors which could limit the estimation pursued in this study. China’s weak intellectual property enforcement has been detailed by a number of different studies (Yasong and Connor 2008; USPTO 2012), and could have effects that vary across technology groups which are beyond the scope of this paper. Additionally, the lack of policy effect could be attributable to inefficient mechanism design. It may simply be that the particular incentives created by the II procurement policy were insufficient to alter patenting behavior.

Finally, the products targeted under the II policy tend to be advanced and capital-intensive technologies, which limit the generalizability of my findings to less technologically advanced fields.

Conclusion

The absence of economically significant policy effects casts doubt upon the effects of the II policy. My findings contradict previous empirical evaluations of the II policy and public policies for innovation. My findings contrast significantly from those by Meng, who found earlier versions of the II policy enacted by the Chinese government to have significant results on innovative activity. They also differ from those of Aschhoff and Sofka, which found public procurement for innovation to be one of the most effective policy tools in motivating innovative activity.

There are also broader implications from these findings. The lack of effects from the market signal and implementation of this policy raises questions of the viability of overall “top-down” public procurement innovation strategies. This paper showed that such policies have no economically significant effects and may cause firms to change the timing of their patenting, rather than motivate new patenting. This has potential implications, particularly for China, which relies heavily on state direction in its commercial research and development.

Implications for future research

Extensions on this research that further explore public procurement for innovation and the II policies broadly are warranted. Overcoming the data availability and methodological limitations outlined earlier would improve the estimation of treatment effects associated with this policy. In particular, data from 2012 and 2013 would improve estimation accuracy and robustness.

Other factors that affect the treatment and control groups unequally may also need to be controlled in this analysis. These could include differing rates of economic growth in regions where research on these technologies are concentrated or knowledge spillover from close proximity of similar firms or research universities.

Appendix: Indigenous Innovation Catalog

2009 National Indigenous Innovation Products

010 100	**COMPUTERS AND APPLICATIONS**
1010001	SUPERCOMPUTER
1010002	HIGH-PERFORMANCE COMPUTERS
1010003	SERVER
1010004	WORKSTATION
1010005	MICRO-COMPUTER
1010006	PORTABLE COMPUTERS
1010007	DIGITAL SIMULATION COMPUTER
1010008	INDUSTRIAL CONTROL MACHINE
1010009	MINIATURE HARD DISK DRIVE
1010010	COMPUTER DIGITAL SIGNAL PROCESSING BOARD
1010011	COMPUTER AND COMMUNICATIONS SECURITY CLASS CARD
1010012	GRAPHICS, IMAGE PROCESSING EQUIPMENT
1010013	VOICE RECOGNITION DEVICE
1010014	NETWORK SWITCHES
1010015	MODEM
1010016	NIC
1010017	IP TELEPHONY GATEWAY
1010018	HIGH-END ROUTERS
1010019	FIREWALL DEVICE
1010020	LAN SECURITY SYSTEM
1010021	FINANCIAL DATA ENCRYPTION MACHINE
1010022	COMMERCIAL POS ENCRYPTION MACHINE
1010023	KAM BANKNOTE COUNTER
1010024	NOTES, COIN RECOGNITION RECEPTORS
1010025	FINGERPRINT COLLECTION SYSTEM
1010026	LASER PHOTOTYPESETTING EQUIPMENT AND SYSTEMS
10200	**COMMUNICATION PRODUCTS**
1020001	DATA SERVICES, NETWORK TEST EQUIPMENT
1020002	SCDMA IS REPEATER
1020003	3G MOBILE COMMUNICATION BASE STATION ANTENNA
1020004	WCDMA AND TD-SCDMA SHARED CORE NETWORK EQUIPMENT
1020005	WCDMA WIRELESS SIDE DEVICE
1020006	TD-SCDMA WIRELESS SIDE DEVICE
1020007	TD-SCDMA TERMINAL TESTER
1020008	RADIO MONITORING AND DIRECTION FINDING POSITIONING SYSTEM

1020009	ETHERNET PASSIVE OPTICAL ACCESS EQUIPMENT
01.02001 m	ILLION MSTP OPTICAL TRANSMISSION SYSTEMS
1020011	SDH FIBER OPTIC TRANSMISSION SYSTEM
1020012	OPTICAL WAVELENGTH DIVISION MULTIPLEXER
1020013	GPS GLOBAL POSITIONING SYSTEM
1020014	GSM CELLULAR MOBILE COMMUNICATION SYSTEM
1020015	CDMA THIRD-GENERATION CELLULAR MOBILE COMMUNICATION SYSTEMS
010 400	MODERN OFFICE EQUIPMENT
1040001	DIGITAL COPIER
1040002	HIGH-SPEED FAX
1040003	VISUAL TELEPHONE
1040004	COLOR LASER PRINTER
1040005	DIGITAL CAMERA
1040006	HIGH-PERFORMANCE SINGLE-LENS REFLEX CAMERA
1040007	MICROFILM CAMERA
010 700	**SOFTWARE**
1070001	OPERATING SYSTEM
1070002	DATABASE MANAGEMENT SYSTEM
1070099	OFFICE SOFTWARE SUITE
1070009	CHINESE INFORMATION PROCESSING PLATFORM
1070020	SECURITY SECURITY SOFTWARE
1070021	SECURITY ANALYSIS SOFTWARE
1070027	AUDIT SOFTWARE
1070028	VIRUS PROTECTION SOFTWARE
1070029	NETWORK MONITORING SYSTEM
1070023	FINANCIAL SOFTWARE
1070025	BASIC GEOGRAPHIC INFORMATION SYSTEM
070 100	**NEW ENERGY AND EQUIPMENT**
7010001	GAS TURBINE / STEAM TURBINE COMBINED CYCLE GENERATING UNIT
7010002	SUPERCRITICAL OR ULTRA-CRITICAL TEMPERATURE, HIGH PRESSURE TURBINE GENERATOR
7010003	PROTON EXCHANGE MEMBRANE FUEL CELL (REMFC)
7010004	PROTON EXCHANGE MEMBRANE FUEL CELL POWER GENERATION DEVICE (REMFC)
7010005	ZINC NICKEL BATTERY
7010006	ZINC SILVER STORAGE BATTERY
7010007	HIGH-CAPACITY LITHIUM-ION BATTERY
7010008	HIGH-ENERGY LITHIUM PRIMARY BATTERIES
7010009	CYLINDRICAL ZINC-AIR BATTERY
7010010	PHOTOVOLTAIC POWER GENERATION SYSTEM
7010011	SOLAR COMPONENTS
7010012	PHOTOVOLTAIC POWER GENERATION CONTROLLER

7010013	PHOTOVOLTAIC INVERTER
7010014	SOLAR INFRARED CONTROL LED UTILITY LIGHTS
7010015	OF THE FLAT-PLATE SOLAR WATER HEATER
7010016	PRESSURE VACUUM TUBE SOLAR COLLECTOR
7010017	SOLAR THERMAL POWER GENERATION SYSTEM
7010018	SOLAR AIR CONDITIONING SYSTEM
7010019	LARGE GRID-CONNECTED WIND TURBINE
7010020	LARGE-SCALE GRID-CONNECTED WIND TURBINE GENERATOR
7010021	LARGE-SCALE GRID-CONNECTED WIND TURBINE BLADES
7010022	LARGE GRID WIND TURBINE ELECTRICAL CONTROL SYSTEM
7010023	WIND FARM CENTRALIZED AND REMOTE MONITORING SYSTEM
7010024	MEDIUM-SIZED WIND TURBINE
7010025	NON-GRID WIND TURBINE CONTROLLER
7010026	BIOMASS CARBONIZATION OF THE PYROLYSIS SYSTEM
7010027	BIOMASS COMPRESSION MOLDING EQUIPMENT
7010028	BIOMASS CIRCULATING FLUIDIZED BED GASIFICATION PLANT
7010029	BIOMASS GASIFICATION SYSTEM EQUIPMENT
7010030	BIOMASS GASIFICATION GENERATOR SETS
7010031	GARBAGE POWER GENERATION EQUIPMENT
7010032	BIOGAS CENTRALIZED GAS SUPPLY SYSTEM
7010033	BIOGAS COMBUSTION ENGINE GENERATOR SETS
7010034	EFFICIENT BIOGAS DESULFURIZATION EQUIPMENT
7010035	GEOTHERMAL POWER GENERATION EQUIPMENT
7010036	TIDAL POWER GENERATION EQUIPMENT
7010037	WAVE POWER GENERATION DEVICE
7010038	SMART POWER SWITCHING EQUIPMENT
7010039	DISTRIBUTION AUTOMATION SWITCHGEAR
7010040	PERMANENT MAGNETIC ACTUATOR VOLTAGE VACUUM CIRCUIT BREAKER
7010041	ORGANIC COMPOSITE INSULATORS
7010042	DRY TYPE CURRENT TRANSFORMER
7010043	HVDC CONVERTER TRANSFORMERS
7010044	SMOOTHING REACTOR
70200	**HIGHLY EFFICIENT ENERGY-SAVING PRODUCTS**
7020001	HIGH-FREQUENCY INDUCTION HEATING POWER SUPPLY UNITS
7020002	EPOXY RESIN DRY-TYPE TRANSFORMERS
7020003	WOUND CORE ADJUSTABLE CAPACITIVE TRANSFORMER
7020004	THREE-PHASE AMORPHOUS ALLOY SEALED DISTRIBUTION TRANSFORMERS
7020005	INTELLIGENT REACTIVE POWER COMPENSATION DEVICE
7020006	HEAT PIPE HEAT EXCHANGER
7020007	HIGH-POWER GAS DISCHARGE LAMP ELECTRONIC BALLAST
7020008	AIR SOURCE HEAT PUMP WATER HEATERS (UNITS)
7020009	LARGE DRY PROCESS CEMENT CLINKER HEAT RECOVERY UNIT

7020010	ELECTRONIC EXPANSION VALVE
7020011	LIQUID RESISTANCE STARTER GOVERNOR
7020012	CENTRAL AIR CONDITIONING SYSTEM, ENERGY-SAVING CONTROL DEVICE
7020013	BLAST FURNACE GAS TURBINE POWER GENERATION UNIT
7020014	CIRCULATING FLUIDIZED BED BOILER
7020015	CONTROLLED ATMOSPHERE FURNACE
7020016	ROTARY KILN DEDICATED PULVERIZED COAL BURNER
7020017	FULLY AUTOMATIC BURNER
7020018	HEAVY OIL BURNERS
7020019	INVERTER ARC WELDING MACHINE
7020020	DIGITAL CONTROL OF INVERTER WELDING MACHINE
7020021	MEMBRANE SEPARATION NITROGEN PLANT
7020022	HIGH-INTENSITY INFRARED RAPID HEATING EQUIPMENT

Appendix: WIPO Technology-IPC Concordance Table

Audio-visual technology	G09F
Audio-visual technology	G09G
Audio-visual technology	G11B
Audio-visual technology	H04N 3
Audio-visual technology	H04N 5
Audio-visual technology	H04N 7
Audio-visual technology	H04N 9
Audio-visual technology	H04N 11
Audio-visual technology	H04N 13
Audio-visual technology	H04N 15
Audio-visual technology	H04N 17
Audio-visual technology	H04N 101
Audio-visual technology	H04R
Audio-visual technology	H04S
Audio-visual technology	H05K
Telecommunications	G08C
Telecommunications	H01P
Telecommunications	H01Q
Telecommunications	H04B
Telecommunications	H04H
Telecommunications	H04J
Telecommunications	H04K
Telecommunications	H04M

Telecommunications	H04N 1
Telecommunications	H04Q
Digital communication	H04L
Digital communication	H04N 21
Digital communication	H04W
Basic communication processes	H03B
Basic communication processes	H03C
Basic communication processes	H03D
Basic communication processes	H03F
Basic communication processes	H03G
Basic communication processes	H03H
Basic communication processes	H03J
Basic communication processes	H03K
Basic communication processes	H03L
Basic communication processes	H03M
Computer technology	G06C
Computer technology	G06D
Computer technology	G06E
Computer technology	G06F
Computer technology	G06G
Computer technology	G06J
Computer technology	G06K
Computer technology	G06M
Computer technology	G06N
Computer technology	G06T

Computer technology	G10L
Computer technology	G11C

Appendix: Indigenous Innovation Firm Awardees

Below are the names of the firms used in the firm-level analysis. As noted earlier in this report, these were selected from the following catalogs:

- 2007: Beijing; Jiangsu
- 2008: Jiangsu; Hebei
- 2009: Beijing; Shanghai; Jiangsu; Wuhan; Guangzhou; Guangdong

2007 Cohort

BEIJING HUAQI INFORMATION DIGITAL TECHNOLOGY COMPANY
BEIJING KINGSOFT SOFTWARE COMPANY
BEIJING SHUGUANG TIANYAN INFORMATION TECHNOLOGY COMPANY
BEIJING VIMICRO PARENT
BEIJING WUYUEXIN INFORMATION TECHNOLOGY COMPANY
CERAD TECHNOLOGY COMPANY PARENT
DATANG MICROELECTRONICS TECHNOLOGY COMPANY
INSPUR ELECTRONIC INFORMATION INDUSTRY COMPANY
JIANGSU LEMOTE TECHNOLOGY CORPORATION
LIGHT COMMUNICATYION BRANCH, DATANG TELECOMMUNICATION SCIENCE AND TECHNOLOGY CO.;DATANG MICROELECTRONICS TECHNOLOGY COMPANY
NANJING LIANHUI COMMUNICATION TECHNOLOGY COMPANY
PANDA ELECTRONICS PARENT

2008 Cohort

GOLDEN VALLEY OPTOELECTRONICS COMPANY
JIANGSU OCEANSOFT SOFTWARE COMPANY
NANJING LINKAGE PARENT
PANDA ELECTRONICS PARENT
NANJING WEIXIANG TECHNOLOGY COMPANY

2009 Cohort

ANFANG GAOKE INFORMATION SECURITY TECHNOLOGY (BEIJING) COMPANY
FOUNDER TECH PARENT
PEKING UNIVERSITY FOUNDER GROUP PARENT COMPANY
BEIJING ANTIAN ELECTRONIC EQUIPMENT COMPANY
BEIJING BRAINAIRE STORAGE TECHNOLOGY
BLUEDON INFORMATION SECURITY TECHNOLOGY COMPANY
CHINA EXPRESS COMPANY

GUANGDONG ESHORE TECHNOLOGY COMPANY
GUANGDONG VTRON PARENT
GUANGZHOU AIVIN AUDIO CO., LTD. GUOGUANG ELECTRIC COMPANY
GUANGZHOU BONSON INFORMATION SYSTEM COMPANY
GUANGZHOU SHENGLONG ELECTRONIC TECHNOLOGY COMPANY
CHENGDU GUOGUANG ELECTRIC COMPANY
GUANGZHOU GUOGUANG ELECTRIC COMPANY
GUOGUANG PARENT COMPANY
HUBEI ZHONGYOU TECHNOLOGY INDUSTRY & COMMERCE COMPANY
JETWAY INFORMATION SECURITY INDUSTRY COMPANY
LEADCORE TECHNOLOGY COMPANY
SHANGHAI ELECTRICAL APPARATUS RESEARCH INSTITUTE PARENT COMPANY
SHANGHAI FOUNDER INFORMATION SECURITY TECHNOLOGY COMPANY
SHANGHAI FUDAN PARENT
SHANGHAI SAND INFORMATION TECHNOLOGY SYSTEM COMPANY
SVA PARENT
SHENZHEN XINGUODU TECHNOLOGY COMPANY
SUZHOU MAIKE NETWORK SECURITY TECHNOLOGY COMPANY
WUHAN FEITIAN INTELLIGENT ENGINEERING COMPANY
WUHAN HAIHENG INFORMATION STORAGE COMPANY
WUHAN ZHONGDI DIGITAL TECHNOLOGY COMPANY
ZHUHAI KINGSOFT SOFTWARE COMPANY

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Chapter 3: Measuring Innovation: How Innovative are Leading Chinese Firms?

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Introduction

Two Chinese telecommunications firms, Huawei and ZTE, are among the most economically and technically advanced in China today. Both firms are commercially successful and have been ranked among the most innovative firms in the world (Fast Company 2010). One measure on which they score particularly well is patent counts. In 2012 ZTE filed 3,906 Patent Cooperation Treaty (PCT) applications and Huawei filed 1,801, making them the first and second largest filers of invention patents at the Chinese State Intellectual Property Office (SIPO). They were also the first and fourth largest recipients of PCT patents in the world.[58] Using patenting as a metric, these firms represent the leading edge of Chinese innovative capabilities.

Despite each firm receiving a large volume of patents, analysts have raised questions about their innovative capacity. Huawei has been accused of stealing technology from a competitor.[59] More broadly, several studies have identified a tendency for Chinese policy to incentivize companies to file large volumes of lower quality patents (McGregor 2010; Lei, Sun et al. 2012; Prud'homme 2012).

This paper examines two research questions:

- What types of inventions do Huawei and ZTE create?
- How innovative are these inventions?

This study analyzes patent data to answer these questions. First, it examines patenting trends in these two firms to understand their areas of technical expertise. Second, it uses a novel metric introduced by Eusebi (2011) and developed by Faith (2013) to evaluate the relative innovativeness of each invention. My research builds upon prior work by applying this “S-curve” analysis method to worldwide patent data and provides suggestive evidence in support of the premises underlying the method.

Firm backgrounds

The two firms selected for analysis in this study represent the vanguard of Chinese business and technological competency. Huawei and ZTE were founded in 1987 and 1985, respectively. They both

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[58] The Patent Cooperation Treaty is a patenting treaty allowing a patent to be filed and protected in 148 countries worldwide. Given the difficulty of being awarded these patents, they signal higher levels of originality than regular invention patents.

[59] For more on this see: Information Age (July 22, 2010). Huawei accused of stealing trade secrets. Information Age, Chandler, M. (October 11, 2012). "Huawei and Cisco’s Source Code: Correcting the Record." https://blogs.cisco.com/news/huawei-and-ciscos-source-code-correcting-the-record/.

manufacture telecommunications technologies, including switching equipment, telecommunications carrier networks, and electronic communications devices.

These firms have rapidly developed in both domestic and international markets. Peilei Fan (2006) describes how they quickly gained domestic market share. In 2012, ZTE was the fifth largest telecom equipment manufacturer measured by revenue in the world (ZTE 2012). It has a number of subsidiaries in the US, Pakistan, Brazil, Germany, and Australia. As of 2012, Huawei had become the world's largest telecommunications equipment manufacturer, with 20 Research and Development (R&D) centers globally. Huawei works with a large number of major telecommunications companies and has customers in 140 countries worldwide (The Economist August 4 2012). Both companies have been recognized as among the most innovative firms worldwide.[60]

Both Huawei and ZTE are latecomers to the international telecommunications manufacturing market and have followed unique technical development paths. Fan (2011) describes both firms making large research and development (R&D) investments to move from imitation to innovation. Fan explains that both of these firms differ significantly from Korean latecomers in the electronics, auto, and semiconductor industries because of their reliance on internal R&D over technology transfer and their ability to innovate (2011). Several studies have identified a general trend among these two firms of producing currently mature technologies and then gradually gaining on leading competitors by slowly developing more innovative products (Fan 2006; Nakai and Tanaka 2010; Fan 2011). By 2012, both firms had filed record numbers of patents.

Literature Review

There is a rich literature on the use of bibliometric[61] measures to evaluate innovative performance among companies and organizations.[62] These measures can also be used to identify the key factors associated with innovation success, as Watts and Porter (1997) have done. There is a wide range of bibliometric measures of innovative inputs and outputs. [63] However, patent counts and characteristics

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[60] Huawei was ranked fifth by *Fast Company* in its "Most Innovative Companies 2010." ZTE was the recipient of Global Telecoms Business Innovation award in 2013. See Anya Kamenetz (2012). "Most Innovative Companies 2010—05_Huawei," Fast Company, at http://www.fastcompany.com/section/most-innovative-companies-2010; ZTE (2013). "ZTE Wins Two 2013 GTB Innovation Awards," at http://wwwen.zte.com.cn/en/press_center/news/201306/t20130606_399734.html.

[61] The OECD defines bibliometric analyses as statistical evaluations of publications. See OECD (2014). Bibliometrics. Glossary of Statistical Terms, OECD.

[62] For examples of metrics used to evaluate innovative performance see Midgley, D. F. and G. R. Dowling (1978). "Innovativeness: the concept and its measurement." Journal of consumer research: 229-242, Koenig, M. E. (1983). "A bibliometric analysis of pharmaceutical research." Research Policy **12**(1): 15-36, Van Raan, A. F. (2005). Measuring science. Handbook of quantitative science and technology research, Springer**:** 19-50.

[63] For a full list see: OECD (2002). Frascati Manual 2002: Proposed Standard Practice for Surveys on Research and Experimental Development, OECD.; Zuniga, P., D. Guellec, et al. (2009). OECD patent statistics manual, Paris: OECD Publications.

are among the few measures of technical outcomes, and patent statistics have been used for decades as signals of technical change in industries and firms.[64]

Determining the value of a patent is highly problematic. Traditionally, authors have relied primarily on the use of patent citations to indicate technical value (Trajtenberg 1990; Karki 1997; Jaffe, Trajtenberg et al. 2000; Hall, Jaffe et al. 2005). However, the use of citations has significant drawbacks. Sherer (1965) shows that value-weighted bibliometric statistics measure inventors' ability to produce average-quality patents, rather than high-quality patents. Previous research has shown that patent citations contain substantial amounts of noise, and almost half of all citations do not correspond to a technical relationship with inventions (Jaffe, Trajtenberg et al. 2000). Inventors and patent attorneys can also manipulate the use of citations in patents they file. [65] Abrams, Akcigit, et al. (2013) show the relationship between citations and patent value is non-monotonic. This calls into question the validity of assessments that use increased citations as markers of increased patent value. Studying patent citation statistics may therefore provide a biased or insufficient understanding of the relative innovative performance of firms. Instead this paper uses data on patents filed, and metrics based on logistic growth curves, henceforth referred to as S-curves.

S-curve models

The use of S-curves (mathematical functions that produce a sigmoid-shaped curve) to evaluate different phenomena is widespread throughout the natural and social sciences. For example, they are used to understand the spread of ideas (Bettencourt, Cintrón-Arias et al. 2006), forecast deliveries of war materials for invasions (Lacey 2011), and measure improvements in technologies (Asthana 1995).[66]

There are a number of models that can be used to model these S-curves. These include cumulative probability distribution functions, Gompertz functions, or logistic functions. As shown by Intepe and Koc (2012) the basic model can be described by the logistic equation:

$$Y_t = \frac{L}{1 + e^{-t}}$$

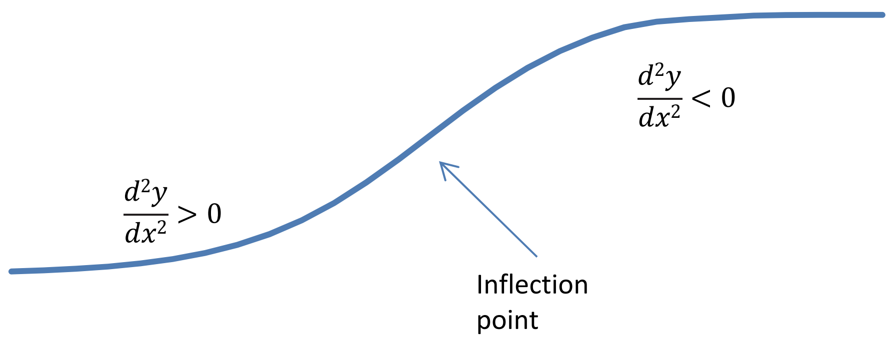
where *e* is the natural logarithm base and *L* is the maximum asymptotic value of Y_t. A stylized example of this curve is shown below in Figure 1.

[64] Examples of the use of patent statistics to measure technical change includes: Schmookler, J. (1954). "Level of Inventive Activity, The." J. Pat. Off. Soc'y **36**: 883. Zuniga, P., D. Guellec, et al. (2009). OECD patent statistics manual, Paris: OECD Publications.

[65] Patent citations can also be assembled to manipulate this metric. Conversation with Chris Eusebi, September 2013.

[66] For a more comprehensive review of areas in which S-curves have been used see Kucharavy, D. and R. De Guio (2007). Application of S-shaped curves. 7th ETRIA TRIZ Future Conference.

Figure 1: Generic S-curve



Use in technology analyses

Extensive research has been conducted using S-shaped growth curves to fit various characteristics of the technology lifecycle and make predictions. For example, growth curves have been used to analyze technology development, diffusion, and forecasting as well as to evaluate strategic technology planning for firms. The use of the S-curve was originally proposed by Foster (1986) in his work, "Innovation: The Attacker's Advantage." Foster also noted that studying the shape of the technology trajectory is important for understanding competitiveness. Ernst (1997) found that S-curves with patent data were appropriate for modeling the diffusion of computerized numerical control (CNC) machine tool technology. The approach captured different development stages of the technology's lifecycle, as well as the connection between patenting activity and subsequent market changes. Several other studies use S-curves to model the market shares of competing technologies (Pistorius and Utterback 1997; Meyer, Yung et al. 1999).

Other authors have shown that S-curve models can inform firms' strategic technology plans. Liu and Shyu (1997) use patent data and S-curve models to analyze a firm's technology development choices. Abraham and Moitra (2001) also use patent analysis because of its ability to provide an understanding of the technical products and processes firms will introduce.

More recently, Wunderlich and Khalil (2004) have conducted technology diffusion analyses using S-curves, and found that technology diffusion rates, or the slopes of S-curves, have been rapidly increasing with new technologies during the 20th century. Daim, Rueda et al. (2006) integrate bibliometrics and patent analysis with forecasting tools, including S-curves, to forecast the development of three emerging technologies (fuel cells, food safety, and optical storage technologies). Intepe and Koc (2012) fit an S-curve to 3-D TV patents to predict future trends in that technology field.

A study by Dattee (2007) challenged the use of the classical, uniform S-curve for modeling technological substitutions, providing counterexamples of technologies that followed more complex trajectories. Rather than dispensing with the approach, however, Dattee recommended that researchers combine it with other forms of analysis and identify bifurcation points where a technology's time-path may deviate from the smooth logistic S-curve shape.

The S-curve model

The primary method used in this paper draws heavily on the work originally conducted by Eusebi (2011)[67] and considers patents as technology bets made by inventors.[68] When one aggregates the number of bets in a technology class over time, an S-curve pattern tends to emerge. The key assumption of Eusebi's model is that inventions earlier along the S-curve, especially those near the takeoff point of the curve, are more innovative and more commercially viable. Innovativeness is then inferred from evaluations of the relative timing of these inventive bets (Eusebi 2011).

The value of earlier knowledge contributions over later contributions has been confirmed using a number of bibliometrics. Newman (2009) shows that earlier academic works receive significantly more citations than their later counterparts. Several other studies emphasize the importance of inventions early along the S-curve. Faith (2013), for example, describes the decisions that technology investors face. The study finds that if a technology is still in the growth phase, it makes sense for investors to attempt to develop new inventions in this field. However, if a technology is mature, investors and inventors should focus their efforts on other technologies that are operating on the growth section of the curve.

The usefulness of early technological bets does have limits. If the place their bets too early, inventors may lack the market and technological conditions necessary to support the full implementation and use of these inventions. Practical examples include Charles Babbage's invention of an early computer, or "difference machine" in the 19th century, or the invention of photovoltaic cells by Charles Fritts in the late 19th century.[69] Both, while highly innovative, lacked mature component technologies and market conditions to allow for their wide adoption. These technologies were too far ahead of their time.

Evaluating the timing of inventive bets also allows researchers to evaluate where a firm operates on the R&D spectrum. Conceptualizing R&D processes as a spectrum from pure research to development, we can roughly characterize bets earlier along the curve to be closer to pure research, while later bets correspond to the development of already-matured technologies. The breadth of a firm's innovative

[67] This work was developed further and used by Faith in her evaluation of Department of Defense Labs. See: Faith, K. S. (2013). "Patterns of Creation and Discovery."

[68] Patent applications have been used extensively in previous literature to measure technical change. Additionally, as Abdih and Joutz (2006) point out Joutz and Gardner (1996) show patent applications represent long-term technological output. See Hausman, J. A., B. H. Hall, et al. (1984). Econometric models for count data with an application to the patents-R&D relationship, National Bureau of Economic Research Cambridge, Mass., USA, Gardner, T. A. and F. L. Joutz (1996). "Economic growth, energy prices and technological innovation." Southern Economic Journal: 653-666.

[69] For more on the Babbage difference machine, see: Grätzel, M. (2000). Powering the planet, Nature Publishing Group, Swade, D. and C. Babbage (2001). Difference Engine: Charles Babbage and the Quest to Build the First Computer, Viking Penguin.

performance can be thought of as its innovative footprint, revealing where along the R&D spectrum a firm concentrates.

Data

All patent data in this research was assembled from the Patent Statistics Database (PATSTAT Database) compiled by the European Patent Office. This database includes the bibliographic information of all patent applications in the world since 1900. These data were coded into component technologies by International Patent Classification (IPC) code. [70] The data fields used in this paper were IPC codes, applications dates, patent granting office, and inventor names and addresses. The data were limited to all priority patent applications since 1950.[71] These applications were then aggregated by IPC code, application month, and year. Data were first assembled for each IPC code at the subclass level (G06N 3) then also at the four digit code levels (G06N 3/01). This aggregation was accomplished for all patents worldwide. Data were then aggregated by year to create patent counts, which were used to generate S-curve models. Descriptive statistics for these data are listed in Panel 1 of Table 1 below.

Table 1: Data descriptive statistics

Panel 1: S-Curves descriptive data

	Mean	**Std Dev.**	**25^{th} %**	**Median**	**75^{th} %**
Yearly IPC class	9.74	56.66	0	0	4

Total number of patent applications: 77,300,000
Total number of IPC classes: 70,889

Panel 2: Firm data

Firm	Number of patent applications[72]
Huawei	51,457
ZTE	36,679
Cisco	19,314
Alcatel	73,886
Juniper	1,971
Aruba	66
Polycom	875
Total	184,248

[70] For a full listing of IPC codes, please see World Intellectual Property Organization (2013). International Patent Classification (IPC) Official Publication.
[71] Priority applications are the first in a series of patent applications filed for a particular invention.
[72]This is the total number of unique patent applications of each firm.

The patents associated with the firms in this study were found using the EEE PPAT harmonized name database, and descriptive statistics of these data are listed in Panel 2 of Table 1. These data were then cross-referenced with each firm's family trees from Dunn and Bradstreet, FBR Asian Company Profiles, and Reuters. The appendix on name harmonization provides further details on this process. Of note, patent applications found for these firms were lower than the self-reported figures listed by Huawei and ZTE.[73] This could be due to a number of reasons, including patenting conducted with no reference to the firm name, or over-reporting by firms.

Methodology

This paper employs descriptive patent data and a novel method pioneered by Eusebi (2011) using S-curves to measure the relative innovative performance of inventors. The research method used involved several steps. First, all patents received by Huawei and ZTE were collected. Second, a RAND-proprietary algorithm was designed to characterize curve take-off points, described below. The method was validated using financial damages awarded from patent infringement cases. Finally, distance calculations were made for each patent in the study. Bibliometric data used include technology classes, filing dates, and patent office information gathered from each patent.

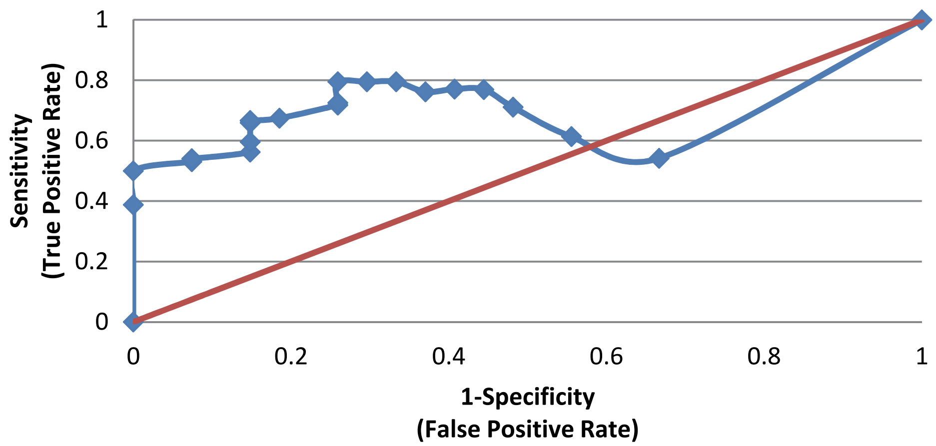
Patent data were assembled at the IPC 4-digit code level. S-curves were characterized using a proprietary algorithm developed at RAND. A key factor in this algorithm is the establishment of a proper coefficient β to characterize S-curves.

Finding the proper coefficient β to characterize curves was accomplished by instituting a Receiver Operating Characteristic (ROC) curve. As described by Lasko, Bhagwat et al. this curve shows the tradeoff of true positive rates to false positive rates for a range of values of β (2005). This curve was calculated by using values of the coefficient β between 60 and 0 and shown below in figure 2. Larger

[73] According to Huawei's website, "As of December 31, 2012, Huawei had filed 41,948 patent applications in China, 12,453 under the Patent Cooperation Treaty (PCT), and 14,494 outside China. Among these applications, 30,240 patents have been granted." According to ZTE's website, "ZTE is one of the leading patent holders among vendors in the telecommunications industry internationally, having filed applications for 48,000 patents globally, with more than 13,000 patents granted. More than 90% of ZTE's patents are invention-related, including a large number of basic patents covering international telecommunications technical standards and core patents covering essential telecommunications technologies." See Huawei. (2014). "Research & Development." from http://www.huawei.com/en/about-huawei/corporate-info/research-development/, ZTE. (March 21, 2013). "ZTE Ranked World No. 1 in Patent Applications for Second Straight Year." from http://wwwen.zte.com.cn/en/press_center/news/201303/t20130321_391025.html.

values of the coefficient β are located on the left side of the curve. The noticeable kinks in the curve occurred at β= 30 and 20. A coefficient of β= 20 was chosen to construct all S-curves used in this study based on two criteria: it maximizes the Youden index while minimizing the distance to the point (0,1) (Akobeng 2007). The Youden index, or distance from the y = x line, indicates the "the point on the curve furthest from chance" (Akobeng 2007). As Akobeng notes, points on the curve closer to (0,1) are more accurate in determining true positives from true negatives (2007). Further details on this process are located in the appendix.

Figure 2: ROC Curve



S-curve start and end points were then constructed following curve characterization. See Table 2 for summary statistics of these S-curves. The average span for the S-curve was determined to be 27.31 years with a standard deviation of 10.46 years. Figure 3 displays the distribution of S-curve span length. The data shown here is only for IPC classes with S-curves, all data for technology classes without S-curves were discarded.

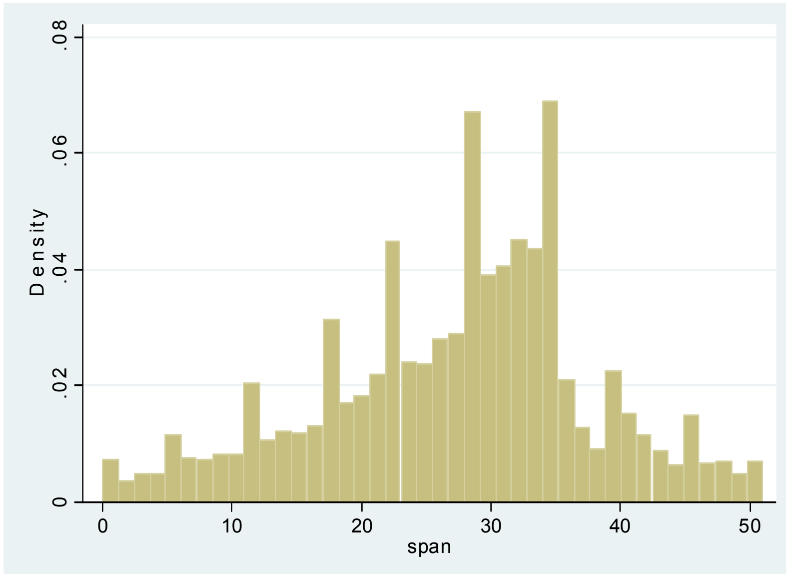
Table 2: S-curve summary statistics

Total number of IPC classes	70,889
Total number of S-curves	19,512

Span descriptive statistics

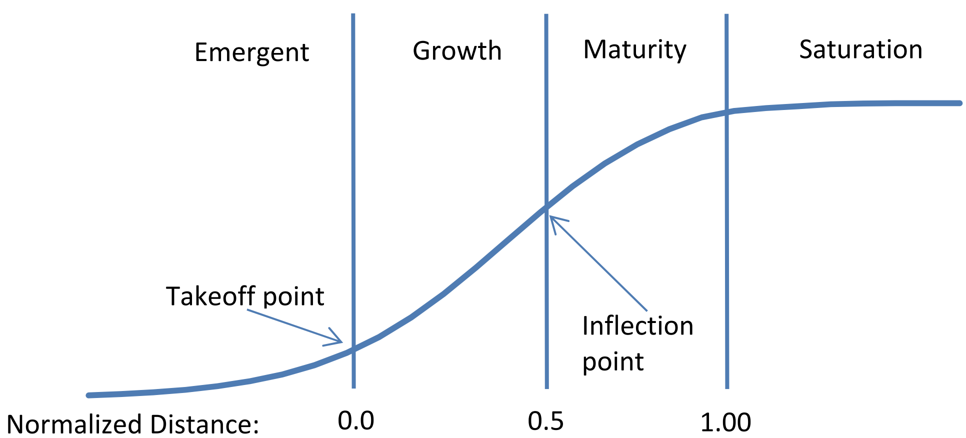
Mean	Std. Dev.	25th percentile	Median	75th percentile
27.31	10.46	21	29	34

Figure 3: Distribution of S-curve spans



Several prior studies separated S-curves into a number of regions to describe the maturity of the technology being studied. This study uses terminology used by previous scholars and separates the curve into four distinct regions: emergent, growth, maturity, saturation (Ernst 1997; Chen, Chen et al. 2010; Faith 2013).

Figure 4: Stages of the S-curve



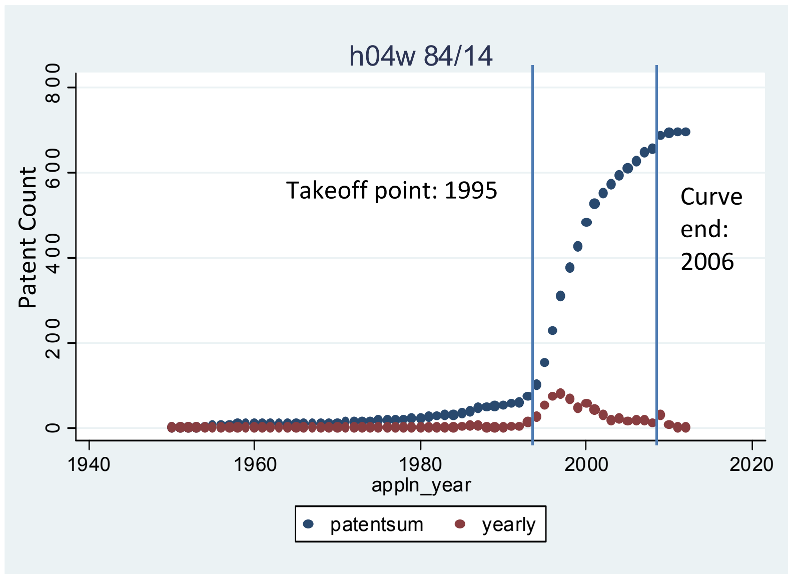
The primary metrics used in this analysis are the distances from curve takeoff point for each patent. Distance calculations were computed for all IPC codes of each patent in my dataset.[74] The time duration between the takeoff point and filing date of each patent was calculated as a fraction of the total span for that patent class. These were then displayed as normalized values for comparison across firms and

[74] Depending on the invention, a patent can have several IPC codes assigned to it.

technology classes. Finally, the IPC class with the shortest distance for each patent was used in all calculations, with other IPC classes ignored.

One example—the technology class H04w 84/14[75]—is illustrated below in Figure 5. The algorithm determined that the takeoff point for this technology class's S-curve was 1995, and whereas the saturation point was 2006. The span for this curve was then determined to be 11 years.

Figure 5: Curve characterization and normalized distance example



S-curve spans were then normalized. ZTE filed application patent number # 1269382 at the Chinese State Intellectual Property Office in 2003. This patent application has four IPC codes assigned to it: H04w 84/14; H04l 12/46; H04b 7/26; H04w 48/14. These were compared to all patent applications filed globally in their respective IPC classes to determine their normalized distance. Of these, H04w 48/14 had the minimum normalized distance and was recorded as the best performing IPC class for this patent.

Validation

Data on financial damages assigned in 141 U.S. patent infringement cases were used to validate the assumption underlying the model that patents filed earlier along the S-curve are of higher value. Just as Newman (2009) found that scientific papers earlier on the S-curve have higher citation counts than those later on the curve, I found that higher damages were paid for infringements of patents earlier along the S-curve. The non-parametric Wilcoxon Signed Rank Test was used to test the median values of four bins: The first three years (emergence), the second seven years (growth), the third seven years (maturity), and the final three years (saturation). Results from this analysis are shown in Table 3.

[75] This IPC code is for inventions associated with wireless local loops or radio local loops.

Table 3: Wilcoxon Test Results comparing normalized distances and patent infringement awards

Descriptive Statistics

	Emerging	Saturation	Growth	Maturity
Median Award Value	5,483,240	767,192	719,395	161,617
Sample Size	62	2	55	22

P-Values

	Emerging	Saturation	Growth	Maturity
Emerging		0.071	0	0
Growth			0.301	0.458
Saturation				0.056

As shown in Table 3, the median value of awards in the Emergence bin is the highest, followed by Saturation, Growth, and Maturity. P-values from this test confirm this result, with the median of the Emerging bin being higher with statistical significance over all other bins. The Growth region's median is also higher than the Maturity region's median with statistical significance at the 10 percent level.

The results of Saturation region merit discussion. Though it has the second highest median value, the p-values show that median values from this bin are not higher than the Saturation or Growth regions with any statistical significance. This is likely due to the small sample size of just 2 observations in this bin. The finding that the further a technology is from its takeoff point, the less likely an infringement case can be made and the lower average damages, provides suggestive evidence that patents received further along the S-curve are less valuable.

Descriptive and S-Curve analyses

In addition to measuring S-curve spans and capturing the time between each patent and the takeoff point of the S-curve for the relevant technology class, I gathered firm data on Huawei and ZTE, as well as five competitor firms (Alcatel, Cisco, Juniper, Aruba, and Polycom) selected based on the similarity of their products and their competitor status. Two of the top competitors to Huawei and ZTE are Alcatel and Cisco (Hoovers 2014). Polycom, Aruba, and Juniper were also included as these firms provide similar products (networking equipment).[76] I studied the distribution of patent applications across technology groups to identify where each of these firms had developed expertise. Data on the types of patents each firm filed, and the countries in which they filed them, also provided valuable information about patent quality.

My descriptive analysis examined patent application counts from Huawei and ZTE, subdivided by patent type, patent office, and IPC codes. Patents were analyzed in two groups: priority and non-priority

[76] Other major firms which also provide telecommunications or networking equipment (Dell, IBM, Hewlett Packard) were not included because they do not focus exclusively telecommunication or networking products.

patents.[77] Priority patent applications provide information about where firms first make inventive bets, including the countries in which they are filing for protection, and the types of patents they file.[78] Non-priority patent applications provide information about where firms are re-filing patents, and about the technology classes and countries in which firms decide to extend protection of existing patents. Researchers can use non-priority patents to identify the inventions that firms believe to be the most valuable or important. IPC class statistics are disaggregated at three levels of detail—subclass (H04b); IPC 2-digit (H04b 10); and IPC 4 digit (H04b 10/19)—as a means of examining the distribution of technical expertise. My descriptive analysis of IPC codes use all codes associated with a patent, rather than the first-assigned IPC code, due to inconsistencies in the way patent data has been recorded historically.[79]

S-curve analysis ranks firms on the performance of their overall portfolio of patents, their most innovative patents, and their filings in recent emergent technologies. Recent emergent technologies were categorized into two groups: those with takeoff points after 1990, and those with takeoff points after 2000.

Analysis

Descriptive analysis

This section examines the patenting trends of Huawei and ZTE to understand the following questions:

- In which countries do these firms file patents?
- What are the overall shares of utility model/invention patent applications filed by these firms?
- In which areas, as designated by IPC classes, has each firm amassed technical expertise?

Huawei Patenting Trends

Approximately sixty percent of Huawei's patent applications are priority applications.

Among the priority patent applications:

- Nearly 100 percent were filed in China.
- 97 percent were invention patents.

[77] Non-priority applications are reapplications of the same invention in other patent offices. An example would be a patent application which is first filed in China, and then later filed in the United States.
[78] Utility model patents are generally of lower quality than invention patents. Chinese utility patents tend to be of particularly low quality. See Moga, T. (2012). China's Utility Model Patent System: Innovation Driver or Deterrent, US Chamber of Commerce.
[79] The State Intellectual Property Office has only within the past seven years begun assigning First IPC codes to identify the primary technological classification of an invention. Because of this, accurate identification of first codes of all patents from these firms would be difficult and may confound estimates.

- Only 1,169 were utility patents, all of which were filed in China, except for 13 in Germany and one in Taiwan.

Among the non-priority patent applications:

- Nearly 11,400, or 55 percent, were filed in China.
- Approximately 17 percent were filed at the European Patent Office (EPO).
- Approximately 15 percent were filed at the U.S. Patent and Trademark Office (USPTO).
- All patents were invention patents, with the exception of 12 utility model patents filed in Germany and 22 in China.

The high shares of invention patents signal the relatively high quality of these inventions. Utility model patents generally tend to be of lower quality. The fact that Huawei also filed nearly 7000 priority patent applications outside of China also indicates the relatively high productivity of their foreign R&D centers.

Among IPC classes, the majority of Huawei patenting falls in the H04L class (“Transmission of digital information”)[80]. Within the H04L class, there is a large number of patent applications in the H04L 12 category (“Data switching networks”). Other large categories include H04W (“Connection management, e.g. connection set-up, manipulation or release”) and H04Q (“methods for selecting switches, relays etc.”) There is also a large number of patent applications in H04W 4 (“wireless communication networks”). Table 4 shows the top five technology classes of Huawei patent applications.

Table 4: Top IPC classes of Huawei patent applications

Rank	IPC subclass	#	% of total	2 digit IPC class	#	% of total	4 digit IPC class	#	% of total
1	h04l	44,214	39.38	h04l 12	25,342	22.57	h04l 29/06	5,248	3.92%
2	h04w	28,465	25.35	h04l 29	11,621	10.35	h04l 12/56	4,661	3.47%
3	h04b	7,921	7.06	h04w 4	4,243	3.78	h04l 12/24	3,126	2.33%
4	h04m	5,743	5.12	h04b 7	3,463	3.08	h04l 12/28	1,755	1.31%
5	g06f	5,298	4.72	h04w 88	2,989	2.66	h04l 12/26	1,373	1.02%

ZTE Patenting Trends

ZTE has a larger number of priority applications that Huawei does, with approximately seventy percent of all patents being priority applications.

Among the priority patent applications:

- Nearly all were filed in China.

[80] All IPC code descriptions from WIPO. (2013). "International Patent Classification (IPC) Official Publication." from http://web2.wipo.int/ipcpub/.

- 94 percent are invention patents, with almost all filed in China. Only 80 were filed outside of China, with approximately 40 filed in Europe and 20 in Korea.
- Only 1400 were utility patents, with only one filed outside of China in Germany.

Among the non-priority patent applications:

- Nearly 72 percent were filed in China, with 13 percent of reapplications to the EPO, and 11 percent of reapplications to the U.S. Virtually all of these are invention patents.
- Only 17 were utility patent reapplications. Of these, 11 were filed in China and six in Germany.
- Virtually all non-priority patent applications filed abroad were invention patents, with the largest numbers in the U.S. (1150), Europe (1400), and Korea (232).

ZTE's applications follow trends similar to those of Huawei. The majority of patents are invention patents and nearly all are filed in China, with relatively few applications abroad.

Among IPC classes, ZTE's patents also follow similar patterns to those of Huawei, as shown in Table 5. The majority of patenting occurs in the H04L category and the H04W category. The five competitor firms also followed similar trends.

Table 5: Top IPC classes of ZTE patent applications

Rank	IPC subclass	#	% of total	2 digit IPC class	#	% of total	4 digit IPC class	#	% of total
1	h04w	24,038	31.14%	h04l 12	11,853	15.36%	h04l 29/06	3,268	5.5%
2	h04l	23,383	30.29%	h04l 29	6,149	7.97%	h04l 12/56	2,835	4.8%
3	h04b	6,489	8.41%	h04w 4	3,663	4.75%	h04l 12/24	2,137	3.6%
4	h04m	4,380	5.67%	h04b 7	3,173	4.11%	h04b 7/26	1,200	2%
5	g06f	3,827	4.96%	h04w 88	3,028	3.92%	h04l 12/26	1,030	1.7%

S- Curve analysis

Using the S-curve technique described earlier, the relative innovativeness of Huawei and ZTE are analyzed by examining their patent applications' normalized distances from S-curve takeoff points. Each firm's patent distances are compared to each other, as well as to those of competitor firms, to examine innovative performance. I used these distances as the primary metric for exploring three key questions:

- What is the general innovative performance of Huawei, ZTE, and other competitors?
- In which technologies do Huawei and ZTE display innovative performance, and how do these compare with the technological specialties of competitor firms?
- How does each firm's innovative performance change over time, and do firms compare across recently emerging technology classes?

Comparing Innovativeness at Huawei and ZTE

The general distribution of innovativeness, measured by normalized distances, is displayed in Figure 6, and Tables 6 and 7, for both Huawei and ZTE. In general, both firms tend to patent relatively late along S-curves. In Figure 6, more innovative firms would be expected to have a distribution of normalized distances further to the left. Using the distributions as a measure, Huawei appears to be slightly more innovative than ZTE, since a higher percentage of its patent applications were made earlier along the S-curves. Both firms have a relatively narrow distribution of innovation, which suggests that the firms only conduct research in a narrow band along the research and development spectrum, and focus on already mature technologies. A firm with a broad distribution is more likely to be conducting original research, closer to the beginning of the S-curve, as well as conducting later incremental or process improvements.

Examining the distributions of normalized patent distances for these two firms more closely, we can also examine their relative performance. Huawei's median normalized distance is smaller than that of ZTE, indicating that a larger fraction of its patents were more innovative. Huawei also had the patent application with the smallest normalized distance (-1), made significantly before the take-off point for its technology class. This indicates that Huawei conducted significantly innovative R&D in at least one technology class.

In general, however, even the most innovative patent applications from these firms were not particularly new, relative to the take-off points for the relevant technology classes. Between them, the firms have only two patent applications at a normalized distance less than 0.3, or in what is considered to be the growth section of the curve. Between these two firms, Huawei appears to have slightly more innovative performance, as measured by the distribution of normalized distances and the number of applications lying in the growth section of the curve.

Figure 6: Huawei and ZTE innovative distributions

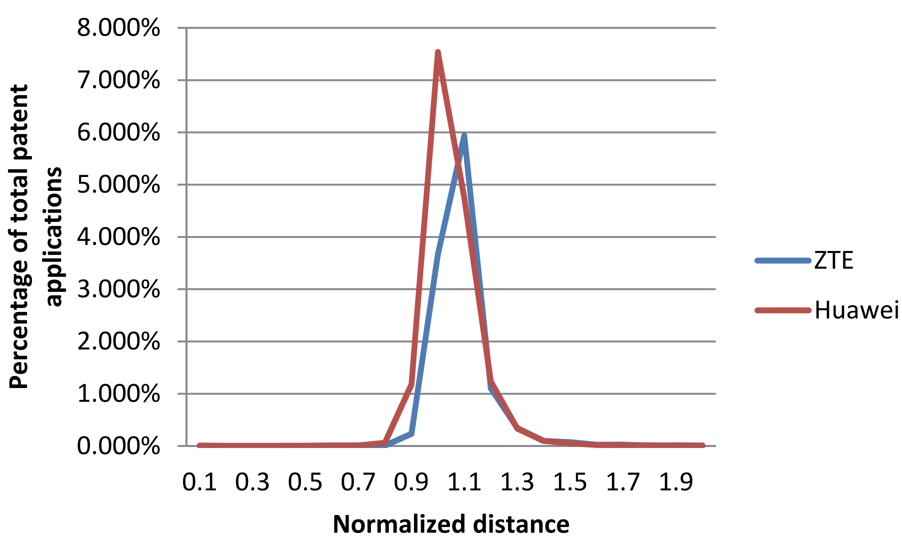


Table 6: Descriptive Statistics

	ZTE	Huawei
Mean	1.044	1.010
Std Dev	0.098	0.118
Min	0.750	-1.000
25th Percentile	1.000	0.956
Median	1.027	1.000
75th Percentile	1.056	1.040
Max	2.231	3.500

Table 7: Count of most innovative patent applications

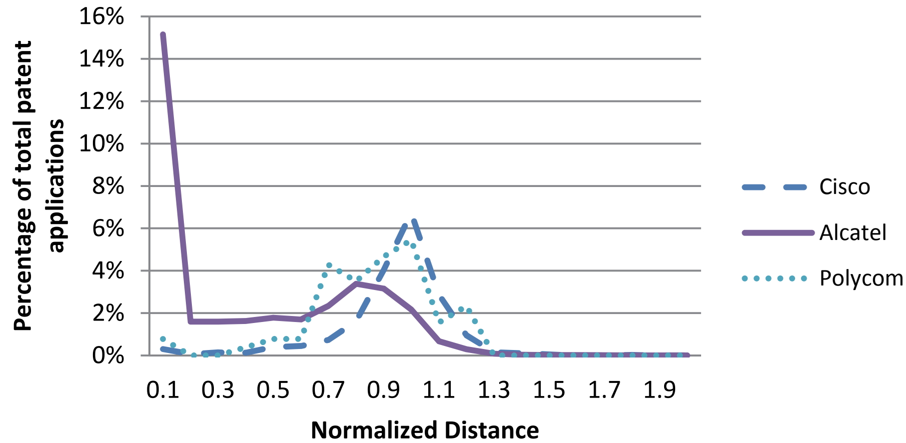
Normalized distance	*ZTE*	*Huawei*
.1	0	2
.2	0	0
.3	0	0

Competitors

Examining the innovative performance of competitor firms provides a benchmark for analysis of the two firms of focus in this study, Huawei and ZTE. Figure 7 plots the distributions of normalized patent distances for five major competitor firms: Cisco, Alcatel, Polycom, Aruba, and Juniper. Tables 8 and 9 present statistics describing their patent distributions, and counts of their most innovative patents (those with the smallest distances). As Figure 7 and Tables 8 and 9 reveal, competitor firms surpass Huawei and ZTE in general innovative performance. Based on the distributions of their patent distances, four competitor firms are more innovative, with only Polycom behind Huawei and ZTE. Similarly, based on counts of low-distance (or highly innovative) patents, most competitor firms rank better than ZTE. Huawei has one patent application at a normalized distance of -1, which causes it to rank third among the firms considered.

The performance of Alcatel in these charts merits attention. Alcatel is the oldest of these firms (founded in 1898) and has merged with several large and very innovative research and development centers, most notably Bell Labs. Because of this, Alcatel's performance is likely to eclipse all competitors, and may not accurately measure its recent innovative performance. This also explains the negative magnitude of the minimum and 25th percentile value for Alcatel patent applications. As noted earlier in this paper, patent applications with highly negative normalized measures are likely to be too early to be considered innovative.

Figure 7: Competitor innovative distributions



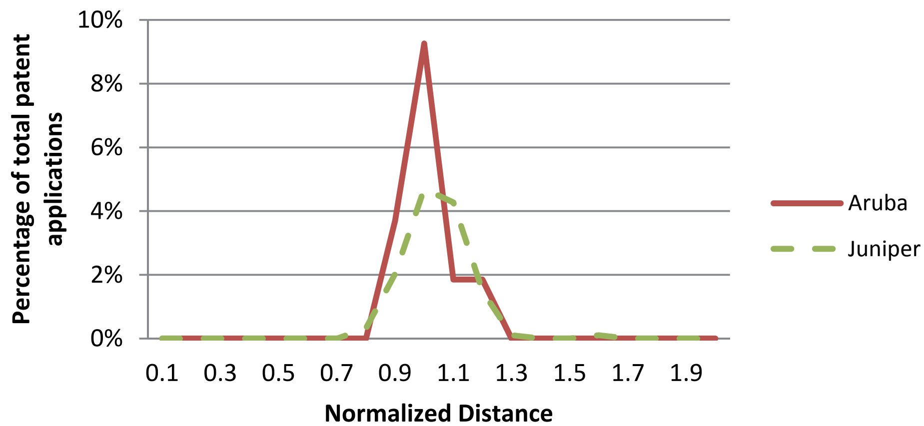


Table 8: Descriptive Statistics

	Cisco	*Aruba*	*Juniper*	*Alcatel*	*Polycom*
Mean	0.89	0.98	0.98	-0.12	0.83
Std Dev	0.23	0.07	0.16	2.15	0.29
Min	-0.75	0.88	0.00	-72.00	-0.50
25th Percentile	0.83	0.94	0.91	-0.48	0.68
Median	0.93	0.98	1.00	0.27	0.84
75th Percentile	1.00	1.01	1.07	0.73	0.97
Max	3.89	1.13	1.57	3.63	2.05

Table 9: Count of most innovative patent applications

Normalized distance	*Cisco*	*Aruba*	*Juniper*	*Alcatel*	*Polycom*
.1	28	0	0	8021	2

.2	6	0	0	845	0
.3	13	0	0	845	0

In Figure 7, broader distributions suggest that a firm's innovation capabilities extend from newly emergent to mature technologies. Both Cisco and Alcatel have a broad distribution of patents. Meanwhile, Aruba and Juniper appear to be similar to Huawei and ZTE; their innovative performance distributions have narrower tails, which indicates that they focus on innovation in relatively mature technologies only.

Examining the most innovative patent counts also provides insight into how innovative these firms are. At normalized distances less than 0.3, which is considered the growth section of the curve, three firms display innovative performance. The most advanced of these three are Alcatel and Cisco. Alcatel has strong performance at curve emergence. This performance is more likely due to its patenting over the past century, rather than its performance in recent decades. Cisco has also posted strong innovative performance, amassing 20 patent applications in the growth section on the S-curve.

The main finding that emerges is that, ranked by the means of their innovative performance distributions, Huawei and ZTE are behind Alcatel, Cisco, Juniper, and Aruba, and display relatively sluggish innovative behavior when compared with competitor firms. Nonetheless, differences between the mean distances calculated for six of the seven firms are quite small, which suggests that their strategic decision-making behavior and innovative capabilities may be quite similar. Alcatel's behavior differs sharply from that of all other firms considered in this study, making it something of an outlier. Comparisons with Alcatel may therefore provide an unduly negative picture of innovation at Huawei and ZTE.

Comparative analysis of innovative patents

Table 10 lists the most advanced patent applications filed by ZTE and Huawei, by IPC class and normalized patent distance.

Table 10: Advanced Huawei and ZTE patent classes

	ZTE		*Huawei*	
Rank	IPC Class	Normalized Distance	IPC Class	Normalized Distance
1	h04w 84/14	0.75	h04q 3/10	-1.00
2	h01q 25/04	0.75	a61f 5/58	-0.50
3	h04b 1/74	0.83	h04q 11/08	0.43
4	h04l 7/04	0.83	h04b 1/48	0.53
5	h04l 12/00	0.84	h03m 13/39	0.55
6	h04l 12/64	0.84	h04j 13/04	0.58
7	h04j 13/00	0.84	h04l 25/14	0.64
8	h04j 13/00	0.84	h04q 7/28	0.67
9	h04m 1/26	0.85	h04l 5/06	0.69

10	g01s 1/02	0.85	h04l 12/00	0.71

The table shows that both firms display innovative performance in H04L (Transmission of digital information), and H04Q (Selecting switches, relays, and selectors) categories. Both firms also have large numbers of filings in these classes, which suggest that they have each developed some technical expertise in these technical areas. ZTE and Huawei do not appear to have specialized in the same particular technologies, however. ZTE's most advanced patent application is h04w 84/14, or an invention involving a wireless or radio local loop. Huawei's most innovative technology is h04q 3/10, dealing with an invention involving a private branch exchange selector.[81] Comparing these patents to the most advanced patents received by competitors, I find that Huawei and ZTE generally lag behind their competitors, as shown in Table 11 below. In particular, ZTE's top-ranking patent applications have poor performance relative to those of competitors.

Table 11: Comparison between Advanced Huawei/ZTE patents and those of competitor firms

IPC Class	Rank among competitor patents in same IPC Class	Normalized distance	Best competitor patent application in this IPC class
	ZTE		
h04w 84/14	11/12	.75	-3.41
h01q 25/04	8/8	.75	-6.13
h04b 1/74	41/53	.83	-.80
h04l 7/04	37/55	.83	-.52
h04l 12/00	50/74	.84	-1.35
	Huawei		
h04q 11/08	13/15	.43	-2.85
h04b 1/48	3/5	.53	.467
h03m 13/39	6/15	.55	.09
h04j 13/04	14/20	.58	-.08
h04l 25/14	21/26	.64	-5

Note: not all top performing patent classes from Huawei and ZTE had competitor applications in each IPC 4 digit subclass

Huawei shows mixed innovative performance in comparison with competitors. In the five technology classes listed in Table 11, Huawei generally lags behind leading competitors, with the most advanced

[81]World Intellectual Property Organization. (2014). "International Patent Classification Codes." from http://web2.wipo.int/ipcpub/#refresh=page.

Huawei patent applications ranked in the middle among those of competing firms. The majority of top-ranking patent applications are from Alcatel. Excluding Alcatel results in very different outcomes, shown in Table 12 below. Both Huawei and ZTE now appear to have leading patents in several fields.

Table 12: Comparison between Huawei/ZTE patents and those of competitor firms, excluding Alcatel

IPC Class	Rank among competitor patents in same IPC Class
ZTE	
h04w 84/14	2/2
h04b 1/74	8/10
h04l 7/04	2/5
h04l 12/00	5/13
Huawei	
h04b 1/48	1/2
h04l 25/14	5/7

Analysis of newly emergent sectors

Examining patent filings in newly emergent technologies can show the degree to which these firms focus on new technologies. For this analysis patent applications were tabulated for each firm in technology classes that had start points after 1990 and 2000, respectively. These are listed in Table 13 below.

Table 13: Recently emergent sectors and firm patent applications

Firm	Patent applications in tech classes with takeoff points between 1990-1999	Patent applications in tech classes with takeoff points between 2000-2009
ZTE	46	1
Huawei	69	2
Cisco	54	0
Alcatel	499	42
Juniper	0	0
Aruba	0	0
Polycom	1	0

ZTE has filed 46 patent applications in sectors that have takeoff points during the 1990s, and only one in technology classes with a takeoff point after 2000. Huawei has filed 69 patents in technology classes with takeoff points between 1990's, and only two in tech classes that have taken off since 2000. ZTE and Huawei lie ahead of their competitors – ahead of Cisco, Juniper, Aruba, and Polycom, but below Alcatel. Cisco has filed 54 patent applications between 1990 and 1999, and none since 2000. The leader in this category is Alcatel. Alcatel has filed 499 patent applications in technology classes that have taken off between 1990 and 1999, and 42 in technology classes that have taken off since 2000. This reveals that Alcatel is a highly active innovator, even in newly emergent sectors. It also shows Huawei and ZTE are making some investment in innovation in newly emergent technologies.

An analysis of the takeoff years of patents filed by these two firms conflicts with Fan's theory (2011) that these firms moved from mature technologies to more cutting edge technologies. All of the patent applications filed by Huawei and ZTE since 2000 have fallen along the saturated region of the S-curve, as shown in Table 13.

Figure 8 plots the upwards trend in normalized patent distances observed over time for Huawei and ZTE. The positive slope of the line suggests that the firms' patent applications have become less innovative over time. Table 14 lists the average slopes of the patent distance trend lines observed for competitor firms. ZTE and Huawei have the fifth and sixth largest slopes among the seven firms. This means that they are decreasing in innovativeness at a faster rate than nearly all of their competitors.

Table 13: Counts of Huawei and ZTE patenting by region since 2000

	Huawei	*ZTE*
Emergent	1	0
Growth	0	0
Maturity	0	0
Saturation	3798	2921

Figure 8: Huawei and ZTE average normalized distance by year

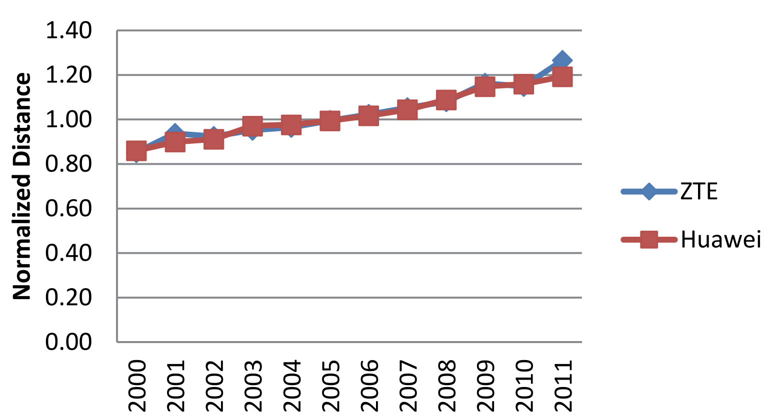


Table 14: Slopes of average normalized distance trend lines by firm

	Slope
ZTE	.032
Huawei	.030
Cisco	.028
Juniper	.029
Polycom	.023
Aruba	.011
Alcatel	.038

Contributions, limitations, and conclusions

Contributions

This study extends the work accomplished by Eusebi by confirming S-curve patterns in worldwide patent data. It also provides support to the assertion that patents filed earlier in the S-curve are of more value and can measure a patent's innovativeness.

In addition, this paper shows the relative innovative performance of major firms in the switching equipment manufacturing sector. It shows that overall Huawei and ZTE are not leaders in innovative performance among the seven firms examined in this study. However, by excluding results from market leaders like Alcatel, these firms do appear to be advanced in certain technologies. This research also contradicts work by Fan, which found that these firms have moved from mature to more cutting edge technologies.

Limitations

As with any paper that uses a novel metric, further validation of the S-curve method, particularly with other data sets, is warranted. Evaluation of overall firm innovativeness may be biased by the history of the firm being evaluated. As shown by innovative results found for Alcatel, firms with long patenting histories may show more innovative performance due to the larger number of bets across a number of technology groups. Hence, analysis of innovative inventors should be conducted with sensitivity towards the firm's history and context. Additionally, as this study uses patent applications as proxies for innovation, it does not include any non-enumerated innovations, including process or management innovations.

Conclusions

This study shows that S-curves can be used to analyze patent data and infer patent value, with patent applications made earlier along relevant technology class S-curves being indicators of higher technical and economic value. The study also shows that researchers can gain rich insights into firms' innovative performance using the normalized distances of patent applications, or the timing of bets relative to technology class take-off points—supplemented with qualitative analyses.

The study applied these methods to the case of the two leading Chinese telecommunications technology firms, ZTE and Huawei, and found that these firms' inventions are primarily in mature technology classes. It further found that the two firms are becoming less innovative over time, despite making some investments in emergent technologies. Previous work theorized that firms would initially focus on already-mature technologies, but later move into ground-breaking innovations (Fan 2011). My findings contradict this conclusion.

Declining innovation metrics could be due to a number of factors. Secrecy is a commonly used method to protect the appropriability of inventions (Cohen, Nelson et al. 2000), and Huawei and ZTE may be engaged in this practice. Laggard performance, particularly in recent years, may also be due to distortionary effects of Chinese policies which incentivize patenting but decrease patent quality.

Appendix: Receiver Operating Characteristic Curves and Optimal Coefficients

To determine the proper coefficient β for the characterization algorithm a Receiver Operating Characteristic (ROC) Curve was used.[82] ROC curves have been used in a number of fields including epidemiology and machine learning to determine the proper test and coefficient when measuring phenomena. A ROC curve provides a plot of two characteristics of each coefficient under examination: the true positive and false positive rates of measures under consideration. This allows the ROC curve to accurately estimate the trade-off in these two characteristics for each coefficient of a test to evaluate a phenomenon.

The two key characteristics of measured are sensitivity and specificity. As described by Lasko, et. al. the sensitivity express the true positive rates, and 1 – specificity the false positive rates (2005). For each coefficient a confusion matrix was constructed measuring the following:

		Detected	
		Positive	**Negative**
Actual	**Positive**	True Positive	False Negative
	Negative	False Positive	True Negative

The sensitivity (true positive rate) is calculated using the following:

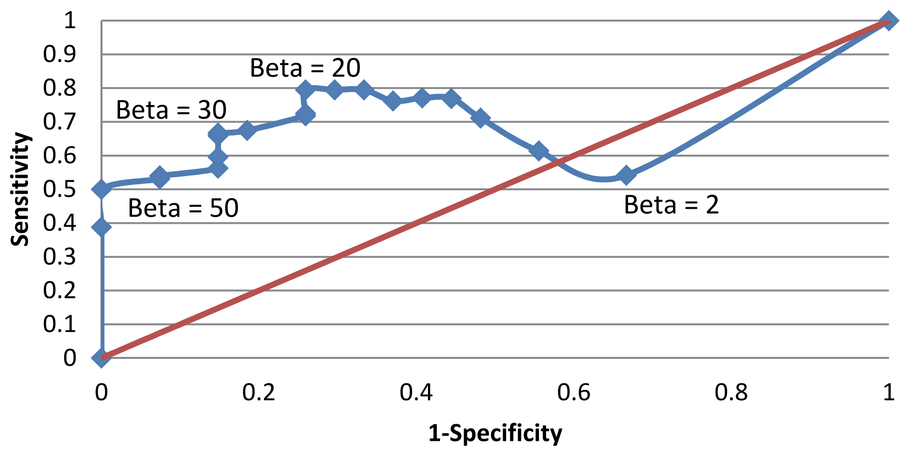
$$\frac{True\ postive}{True\ postive + False\ Negative}$$

The specificity (1-false positive rate) is calculated using the following:

$$\frac{False\ postive}{False\ postive + True\ Negative}$$

These are then used to create a plot which shows the tradeoff of these two characteristics for each coefficient examined. The following ROC curve was assembled by plotting these metrics for each coefficient β:

[82] For more on ROC curve construction and interpretation see Bewick, V., L. Cheek, et al. (2004). "Statistics review 13: receiver operating characteristic curves." Critical care **8**(6): 508, Lasko, T. A., J. G. Bhagwat, et al. (2005). "The use of receiver operating characteristic curves in biomedical informatics." Journal of biomedical informatics **38**(5): 404-415.



The line y = x is added to indicates performance of a test which is equivalent to guessing.

Using the ROC curve above it is easy to see that decreasing levels of the coefficient β result in higher rates of false positives. The two noticeable steps in the function occur at β = 30 and β = 20. Of note is β = 2, which yields higher levels of false positives than true positives (below the y = x line). This intuitively makes sense – as the coefficient drops closer to zero the tradeoff between true positives and false positives drops to essentially a random guess.

Finding the optimal coefficient level can also be accomplished by using the Youden statistic (J). This is calculated by the following:

$$J = Sensitivity + Specificity - 1$$

The Youden statistic shows the distance from the line Y = X. A value of zero indicates that this coefficient provides identical proportions of positive results for technology classes with and without S-curves. A Youden statistic of 1 indicates that the coefficient yields no false positives or negatives. The optimal coefficient on the ROC curve will therefore have the largest Youden statistic.

The point (0,1) also has special significance on the ROC curve. It is the coefficient which yields only true positives and no false negatives, or the “perfect fit point.” Distances to the point (0,1) are calculated using the standard Euclidian distance formula:

$$D = \sqrt{(1 - Sensitivity)^2 + (1 - Specificity)^2}$$

The sensitivity and specificity scores, as well as the Youden Index scores and distance calculations are shown for all coefficients in Table 15 below. Additionally the coefficient which maximizes the Youden statistic and minimizes the Euclidian distance is highlighted.

Table 15: Coefficients Beta and associated sensitivity, specificity, distance to (0,1) and Youden Statistics

Beta	*Sensitivity*	*Specificity*	*1-specificity*	*Distance to (0,1)*	*Youden*
60	0.387	1	0	0.612	0.387
50	0.5	1	0	0.500	0.5
42	0.530	0.925	0.074	0.475	0.456
40	0.54	0.925	0.074	0.466	0.465
38	0.54	0.925	0.074	0.466	0.465
36	0.562	0.851	0.148	0.462	0.414
34	0.595	0.851	0.148	0.431	0.447
32	0.659	0.851	0.148	0.372	0.510
30	0.667	0.851	0.148	0.365	0.518
28	0.667	0.851	0.148	0.365	0.518
26	0.674	0.814	0.185	0.375	0.489
24	0.717	0.740	0.259	0.383	0.458
22	0.725	0.740	0.259	0.378	0.465
20	0.794	0.740	0.259	0.331	0.535
18	0.794	0.704	0.296	0.360	0.498
16	0.794	0.667	0.333	0.391	0.461
14	0.761	0.629	0.370	0.440	0.391
12	0.770	0.593	0.407	0.467	0.363
10	0.769	0.556	0.444	0.501	0.324
8	0.711	0.518	0.481	0.561	0.229
6	0.651	0.556	0.444	0.786	0.207
4	0.614	0.444	0.556	0.677	0.058
2	0.542	0.333	0.667	0.809	-0.125

Appendix: Name Harmonization and Firm Identification

Finding all company names associated with Huawei and ZTE presented a significant challenge. When patents are filed, not all are labeled with the parent' companies' names, which complicates accurate identification of all patents associated with a given corporate entity. Company names are also frequently misspelled. Applications often omit firm keywords, or only identify the firm's address. Additionally, the byzantine nature of parent and subsidiary companies further complicates this issue.

To overcome these challenges, I used two approaches. First, I used the name harmonization database tables, or EEE PPAT, to identify related firm names. The database harmonizes names and eliminates misspellings that are frequently encountered. Finally, I identified all subsidiaries associated with parent companies by using the names listed on the Dunn & Bradstreet and FBR Asian Company profiles. The subsidiary listings for each company are shown below:

Huawei
HUAWEI TECH INVESTMENT CO LTD
SUNDAY COMMUNICATIONS LTD
HUAWEI TECHNOLOGIES CO LTD
SHENZHEN HUAWEI COMMUNICATION CO LTD
SHENZHEN HUAWEI ELECTRIC CO LTD
XUNWEI TECHNOLOGIES CO LTD
JUXIN TECHNOLOGY CO LTD
SHANDONG HUAWEI COMMUNICATION TECHNOLOGY CO LTD
ZHEJIANG HUAWEI COMMUNICATION TECHNOLOGY CO LTD
HUAWEI TECHNOLOGY SERVICE CO LTD
SHENZHEN HUAWEI TECHNOLOGY SOFTWARE CO LTD
HUAWEI TECHNOLOGIES CANADA CO LTD
SHENZHEN HUAWEI TECHNOLOGY SERVICE CO LTD
SHENZHEN HUAWEI COMMUNICATION TECHNOLOGIES CO LTD
CHINA NETCOM NATIONAL LAB FOR BROADBAND APPLICATION CO LTD
SHENZHEN HUAWEI TECHNICAL SERVICES CO LTD
HUAWEI TECHNOLOGIES COMPANY NIGERIA LTD
HUAWEI OMAN
HUAWEI TECHNOLOGIES UGANDA CO LTD
HUAWEI TECHNOLOGIES CO LTD - BEIJING OFFICE
HUAWEI TECHNOLOGIES CO LTD - FUJIAN OFFICE
HUAWEI TECHNOLOGIES CO LTD - GANSU OFFICE
HUAWEI TECHNOLOGIES CO LTD - GUANGDONG OFFICE
HUAWEI TECHNOLOGIES CO LTD - GUANGXI OFFICE
HUAWEI TECHNOLOGIES CO LTD - GUIZHOU OFFICE
HUAWEI TECHNOLOGIES CO LTD - HEFEI OFFICE
HUAWEI TECHNOLOGIES CO LTD - HAINAN OFFICE
HUAWEI TECHNOLOGIES CO LTD - HEBEI OFFICE

HUAWEI TECHNOLOGIES CO LTD - HEILONGJIANG OFFICE
HUAWEI TECHNOLOGIES CO LTD - HUBEI OFFICE
HUAWEI TECHNOLOGIES CO LTD - JIANGSU OFFICE
HUAWEI TECHNOLOGIES CO LTD - JILIN OFFICE
SHENZHEN HUAWEI INFORMATION TECHNOLOGIES CO LTD
SHENZHEN HUAWEI COMMUNICATION EQUIPMENT INSTALLING CO LTD
SHENZHEN HUAWEI IC DESIGN & INSTALLING CO LTD
HUAWEI TECHNOLOGIES COOPERATIEF UA
SHENZHEN HUAWEI TECHNOLOGIES SERVICE CO LTD
SHENZHEN HUAWEI NEW TECHNOLOGIES CO LTD
SHENZHEN HISILICON TECHNOLOGIES CO LTD
SHENZHEN HUAWEI ANJIEXIN ELECTRIC CO LTD
SHENZHEN HUAWEI TRAINING INSTITUTE CO LTD
SHENZHEN HUAWEI INFORMATION SYSTEM ENGINEERING CO LTD
SHENZHEN HUAWEI INVESTMENT HOLDINGS CO LTD
HUAWEI TECHNOLOGIES CO LTD - JIANGXI OFFICE
HUAWEI TECHNOLOGIES CO LTD - LIAONING OFFICE
HUAWEI TECHNOLOGIES CO LTD - SHANDONG OFFICE
HUAWEI TECHNOLOGIES CO LTD - SHAANXI OFFICE
CHINA NETCOM GROUP BROADBAND SERVICE APPLICATIONS LTD CORP FOR NATIONAL
ENGIN EERING LABORATORY
COSMOBIC TECHNOLOGY CO LTD
GUIZHOU IMART INFORMATION SUPER MARKET ITEM DEVELOPING CO LTD
HUAWEI DIGITAL TECHNOLOGY CO LTD
HUAWEI SYMANTEC TECHNOLOGIES CO LTD
CHENGDU HUAWEI SYMANTEC TECHNOLOGIES CO LTD
CHENGDU HUAWEI STORAGE & NETWORK SECURITY CO LTD
SHANGHAI YUMENG COMMUNICATION TECHNOLOGY CO LTD
HUAWEI TECHNOLOGIES SWITZERLAND AG
HUAWEI SA
HUAWEI TECH (UAE)
HUAWEI TECHNOLOGIES CO LTD HEFEI BRANCH OFFICE
HUAWEI TECHNOLOGIES CO LTD JINAN OFFICE
HUAWEI TECHNOLOGIES CO LTD XIAN BRANCH OFFICE
SHENZHEN HUAWEI ANJIEXIN ELECTRICITY CO LTD
HUAWEI TECHNOLOGIES CO LTD CHANGCHUN BRANCH OFFICE
HUAWEI TECHNOLOGIES CO LTD FUZHOU BRANCH OFFICE
HISILICON TECHNOLOGIES CO LTD
HUAWEI TECHNOLOGIES CO LTD CHONGQING BRANCH
HUAWEI TECHNOLOGIES CO LTD HANGZHOU OFFICE
HUAWEI TECHNOLOGIES CO LTD GUANGZHOU BRANCH
HUAWEI TECHNOLOGIES CO LTD GUIYANG BRANCH OFFICE
HUAWEI TECHNOLOGIES CO LTD KUNMING BRANCH OFFICE
HUAWEI TECHNOLOGIES CO LTD LANZHOU BRANCH OFFICE
HUAWEI TECHNOLOGIES CO LTD SHANGHAI BRANCH

HUAWEI TECHNOLOGIES CO LTD SHIJIAZHUANG BRANCH OFFICE
HUAWEI TECH INVESTMENT SAUDI ARABIA CO LTD
M4S WIRELESS LIMITED
SHENZHEN LEGRIT TECHNOLOGY CO., LTD.
JUXIN TECHNOLOGIES CO. LTD
SHANGHAI MOSSEL TRADE CO. LTD.
SHENZHEN ANJIEXIN ELECTRIC CO.,LTD.
SHENZHEN HUAWEI TRAINING COLLEGE CO., LTD.
SHENZHEN SMARTCOM BUSINESS CO., LTD.
FUTUREWEI TECHNOLOGIES, INC.

ZTE

SHENZHEN ZHONGXING MOBILE COMMUNICATION EQUIPMENT CO LTD
BEIJING ZHONGXINGXIN COMMUNICATIONS EQUIPMENT CO LTD
SHENZHEN KANGXUN CO LTD
SHANXI ZHONGXIN COMMUNICATIONS EQUIPMENT CO LTD
XI'AN ZTE JINGCHENG COMMUNICATION CO LTD
GUANGZHOU WESTERN TELECOM SYSTEM & SOFTWARE CO LTD
ZTE HRVATSKA DOO
SHENZHEN ZHONGXING MOBILE COMMUNICATION EQUIPMENT CO LTD
SHENZHEN ZTE KANGXUN ELECTRONICS CO LTD
SHENZHEN ZTE SOFTWARE CO LTD
ANHUI YALONG COMMUNICATION TECHNOLOGY CO LTD
SHENZHEN XINGFEI SCIENCE & TECHNOLOGY CO LTD
ZTE ISTANBUL TRADING LTD
ZTE CORP BULGARIA LTD
ZTE DEUTSCHLAND GMBH
ZTE POLAND SP ZOO
SHENZHEN ZTE LIWEI TECHNOLOGY CO LTD
ZTE CANADA INC
ZTE NETHERLANDS BV
ZTE GHANA LTD
SHENZHEN ZTE WIRELESS COMMUNICATION CO LTD
SHENZHEN HONGDE BATTERY CO LTD
ZTE NIGERIA INVESTMENT LTD
ZTE (HK) LTD
ZTE SWEDEN AB
ZTE INDONESIA PT
ZTE SOFT TECHNOLOGY CO LTD
ZTE CORPORATION SOUTH AFRICA (PTY) LTD
ZTE CORP - ABU DHABI
SHENZHEN FUDEKANG ELECTRONICS CO LTD
SHENZHEN ZHONGXING MANAGEMENT CONSULTING CO LTD
SHENZHEN ZHONGXING XINDI TELECOM EQUIPMENT LTD
SHENZHEN TECHASER TECHNOLOGIES CO LTD
SHENZHEN ZHONGXING INT'L INVESTMENT CO LTD

SHENZHEN ZHONGXING WEIXIANTONG EQUIPMENT CO LTD
SHENZHEN ZTE MOBILE COMMUNICATION CO LTD
NANJING ZTESOFT TECHNOLOGY CO LTD
SHENZHEN ZTE JIXUN COMMUNICATION CO LTD
SHENZHEN ZTE SOFTWARE CORP
WUXI ZHONGXING OPTOELECTRONICS TECHNOLOGY CO LTD
SHANGHAI ZTE TECHNOLOGIES LTD
ZTE CORP
ZTE CORP IRTIBAT BUROSU
HUNGARIAN COMMERCIAL REPRESENTATIVE OF ZHONGXING HIRADASTECHNIKAI RT
ZTE TECHNICAL SERVICES CO LTD
ZHONGXING TELECOM PAKISTAN PVT LTD
ZTE KAZAKHSTAN
ZTE CORP KENYA
ZTE SUDAN CORP SUDAN
ZTE CORPORATION ALGERIA EURL
CORPORATION ZTE- COMMUNICATION TECHNOLOGIES
ZTE NEPAL
APENVISION LTD
HENGYANG ZTE NET INFORMATION TECHNOLOGY CO LTD
NANJING ZTE HEERTAI HOTEL INVESTMENT MANAGEMENT CO LTD
NETEX CCAYMAN HOLDING CO LTD
SHANGHAI ZTE COMMUNICATION TECHNOLOGY CO LTD
SHENZHEN BAIWEI TECHNOLOGY CO LTD
SHENZHEN TECHASER TECHNOLOGY CO LTD
SHENZHEN ZHONGXING WXT EQUIPMENT CO LTD
SHENZHEN ZTE INT'L INVESTMENT CO LTD
SHENZHEN ZTE JIXUN COMMUNICATIONS CO LTD
SHENZHEN ZTE MANAGEMENT CONSULTING CO LTD
SHENZHEN ZTE WULIAN TECHNOLOGY CO LTD
WUXI ZTE OPTOELECTRONIC TECHNOLOGY CO LTD
XI'AN JINGCHENG COMMUNICATION (HONG KONG) CO LTD
XIAMEN ZTE SOFTWARE CO LTD
XIAN ZTE JINGCHENG TECHNOLOGY CO LTD
XINXUN INT'L (HONG KONG) CO LTD
ZTE ALBANIA SH P K
ZTE CO LTD BEIJING INSTITUTE
ZTE CO LTD CHENGDU POWER COMMUNICATIONS BRANCH
ZTE CO LTD HEFEI BRANCH OFFICE
ZTE CO LTD INNER MONGOLIA BRANCH
ZTE CO LTD NANJING BRANCH
ZTE CO LTD
ZTE CO LTD
ZTE CO LTD ZHENGZHOU BRANCH OFFICE
ZTE CORP PARAGUAY SA
ZTE GROUP FINANCE CO LTD

ZTE INTERNACIONAL SA
ZTE SWITZERLAND AG
ZTE CO LTD WUHAN BRANCH OFFICE
NANJING ZTE MOBILE COMMUNICATION CO LTD
SHANGHAI HEERTAI HOTEL INVESTMENT MANAGEMENT CO LTD
ZTE CO LTD HARBIN BRANCH
ZTE CO LTD SHANXI BRANCH
GUANGDONG NEWSTART TECHNOLOGY SERVICE CO., LTD.
NANJING ZTE SPECIAL SOFTWARE LTD.
ANHUI WANTONG POST CO.,LTD.
SHENZHEN FUSIDA TECHNOLOGY CO., LTD.
SHENZHEN ZTE INTEGRATED TELECOM LTD.
SHENZHEN ZTE MOBILE TELECOM CO., LTD.
WUXI ZHONGXING OPTOELECTRONICS TECHNOLOGY CO., LTD.
ZTE ISTANBUL TELEKOMUNIKASYON SANAYI VE TICARET LTD STI
ZTE PORTUGAL - PROJECTOS DE TELECOMUNICAÇÕES, UNIPESSOAL, LDA
ZTE (MALAYSIA) CORPORATION SDN. BHD.
ZTE DEVELOPMENT CO LTD
WOOTION TECHNOLOGY CO., LTD.
ZTE FRANCE SASU
ZTE KANGXUN TELECOM CO. LTD.
ZTE MICROELECTRONICS TECHNOLOGY CO., LTD.
ZTE SUPPLY CHAIN CO., LTD
ZTE TECHNICAL SERVICES CO., LTD.
ZTE TELECOM INDIA PRIVATE LIMITED
ZTE WISTRON TELECOM AB
ZTESOFT TECHNOLOGY CO., LTD.

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