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China's agricultural patents: How has their value changed amid recent patent boom?

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ABSTRACT

Patent applications have surged in China over the past two decades. Has the application boom been accompanied by a simultaneous drop in the value (quality) of the patents? Our research examines this question by analyzing invention patents in agriculture. Using data from China's State Intellectual Property Office (SIPO) for patents between 1985 and 2005 that had been granted before January 2011, we conduct duration analysis of patent life span and the length of patent renewal with the Weibull and Cox Proportional Hazard modeling respectively. The results show that the value of Chinese agricultural patents, measured by their life span and renewal length, has been improving, although foreign grants are still maintained significantly longer than domestic ones. For domestic grants, private entities, especially companies, are more likely to have a longer patent protection period than public entities. Furthermore, patent value varies significantly across different technological fields, with grants to inventions in complex and emerging technologies such as agricultural biotechnology and agricultural chemicals demonstrating higher value than others. The findings have implications for understanding the impacts of China's innovation policy on global patenting activities as well as China's innovation trajectory in agriculture and other sectors.

1. Introduction

Patent applications for agricultural innovations have surged in China in the past two decades as agricultural technology has become more science-based. The number grew by almost 35 folds between 1985 and 2009. The rise is against the backdrop of China's ambition as well as efforts to a patent powerhouse. Indeed, China is striving to transform itself into an innovation-oriented nation by 2020, and, furthermore, a world leader in science and technology by 2050 (Suttmeier et al., 2006). To this end, the Chinese government has taken various measures to strengthen its indigenous innovation capabilities. For example, it has increased its expenditure on R&D,[1] adopted tax and other incentives to promote innovation, raised budget for public research institutions, and implemented a patent subsidy program at the regional level. These have led to the explosive growth of Chinese patenting activities. For example, the volume of patent applications has grown by 84 folds in 25 years after the installation of the patent system, and in 2011 total domestic applications for invention patents with China's State Intellectual Property Office (SIPO) reached 415,829, making China the world's top patent producer, surpassing the United States and Japan (Economics and Series, 2012).

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[1] The data from China's National Bureau of Statistics indicates that the R&D spending as a percentage of GDP rose from 0.6% in 1996 to 1.75% by 2010, and its share of global R&D spending increased from 9.1% in 2008 to 12.3% in 2010, just behind the United States, Japan and the European Union.

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However, there have been concerns of a patent bubble being formed, that is, the increasing number of applications may lead to a significant drop in the value (or quality) of patents—mainly their potential economic value like other intangible assets. This has happened in the United States and the European Union (Kortum and Lerner, 1999; Hall and Ziedonis, 2001; Jaffe and Lerner, 2004; van Pottelsberghe de la Potterie and van Zeebroeck, 2008; van Zeebroeck, 2007; Archontopoulos et al., 2007). For instance, using citation-based measures, Buccola and Xia (2004) detect an apparently substantial decline in the average quality of agricultural biotechnology patents in the United States van Pottelsberghe de la Potterie and van Zeebroeck (2008) compute a scope-year index based on patent families and renewals showing that the average value of patents filed at the European Patent Office (EPO) increased in the early 1980s but had subsequently decreased from the mid-1980s to the mid-1990s. According to OECD's most recent composite index, rising patenting activity at the EPO has been accompanied by an average 20% decline in the patent quality between the 1990s and 2000s (OECD Science, 2011).

In this context, to examine the changing value of Chinese agricultural patents could provide a window to observe whether China has experienced a similar decline of its patent quality amid the quantitative boom and points to the likelihood whether China will be an innovation powerhouse in both the quantitative and qualitative terms. Agricultural patents are selected because innovation on agriculture has been an engine of agricultural growth in China over the past 30 years like many developed countries (Postlewait et al., 1993). The Chinese government considers agricultural technology a major solution to the nation's food security problem. And innovation is of significance to the sustainable development of China's agriculture and economy as a whole. While of all industries agriculture has exhibited the most significant relative technological advantage in Chinese patenting activities (Liegsalz and Wagner, 2013), agricultural innovation has not been given considerate attention in the study of China's scientific and innovation performance (Huang, 2010; Fu et al., 2011; Guan and Ma, 2007). Moreover, while the explosive growth of Chinese patenting has been well documented and examined (Huang, 2010; Zhou and Stembridge, 2010; Hu, 2009; Li, 2012), the patent's value issue has yet to be understood thoroughly (Ma et al., 2009; Huang, 2012). To fill these gaps, we will use two critical indicators—patent life span and the length of patent renewal—to measure Chinese agricultural patent value. We will pay particular attention to agricultural biotechnology (ag-biotech), because innovation on platform and enabling biotechnologies, transformation and gene-transfer techniques, and genomics has strongly influenced the development of new agricultural technologies. Indeed, patented innovation has become part of the culture of biological research given its increasingly capital-intensive and risky nature (Buccola and Xia, 2004).

The rest of the paper is organized as follows. The next section describes China's patent system and the patent growth in the agriculture sector. Section 3 reviews relevant literature and formulates research questions to be examined. Section 4 introduces research method, explains how survival analysis is employed to study the patent's survival and renewal records. We also perform descriptive analysis, parameterize the survival models and then present and discuss the estimations in Section 5. Section 6 concludes the study and considers some implications of the results for the measurement and evaluation of innovation management (not only in agriculture) in China.

2. China's patent system and the patent boom in the agriculture sector

2.1. China's patent system

On March 12, 1984, China promulgated its first patent law granting three types of patents: invention, utility model and design patents.[2] The patent law went in effect on April 1, 1985, marking the official beginning of the patent system in the People's Republic. Thus far, the patent law has been amended three times—in 1992, 2000 and 2008 respectively. Under the impetus of these amendments, the quality criteria for patent grants have been gradually raised, which in turn has influenced patenting activities.

The first amendment was a response to foreign pressure to expand the scope, extend the duration and strengthen the protection of patent rights (Yang, 2003). Not only was the duration of invention patent protection extended from 15 to 20 years, but notably food and beverage, pharmaceutical and chemical inventions, and microbiological products and processes became patentable. From then on, inventors could seek patent protection for many agricultural innovations such as agricultural chemicals, pesticides, animal drugs and gene sequences. China became a member of the Patent Cooperation Treaty (PCT) in 1994 and joined the World Trade Organization (WTO) in 2001. The second amendment was to harmonize China's patent law with the TRIPS requirements such that resident and non-resident entities enjoy equal treatment in obtaining patent rights. Finally, the third amendment in 2008 was likely driven by China's determination to diminish the so-called "garbage patents" under the existing law and more importantly to enhance its indigenous innovation capabilities. The most noticeable change of the amendment is to endorse absolute novelty as the criteria so as to raise the bar of patentability. This change also pushes inventors to file applications as early as possible. In all, these amendments have made the Chinese patent system close to that in Europe and Japan (Hu, 2009). As the quality criteria for patent examination have been raised, the value of grants should have improved over time as well.

As the national patent office, the State Intellectual Property Office (SIPO) in Beijing handles all applications for examination. Upon receiving an application, SIPO performs preliminary examination to ensure it meets the statutory filing requirements. If an invention patent application passes the preliminary examination, SIPO usually publishes it within 18 months from the first Chinese filing date or priority filing date, unless the applicant requests an earlier publication or withdraws the application. The preliminary examination and publication of the application establish invention priority so as to preclude

[2] Compared to invention patent application that requires a substantive examination for the higher patentability requirement, utility models and design patents are typically "small and incremental innovations" and are usually seen as low-quality, and as such they are not included in the following discussion.

other similar claims and to enable the applicant to charge fees for the use of the invention. Before the invention patent can be granted, it needs to pass a substantive examination upon applicant's request within 3 years from the first Chinese filing date. If the applicant does not ask for the examination in time, the application is deemed to be withdrawn voluntarily. Throughout the entire examination period, which, according to a SIPO survey in 2008, took an average of 25.8 months (SIPO, 2008), the applicant may still have opportunities to amend the application within the scope of the initially submitted documents. Of course, the applicant may withdraw the application at any time during the examination. After substantive examination, SIPO decides whether to grant a patent and publish the granted patent. If the application is finally approved, the term for invention patent protection is 20 years, counting from the filing date.

The basic application fee is RMB950 (about $156 as of October 2013), and the fee for substantive examination is RMB2500 ($410). The annual renewal incurs a fee that increases over time in the duration of the patent life. The fee for maintaining a patent for the first 3 years is RMB900 ($148), which rises to RMB1200 ($197) between the 4th and 6th years. Starting from the 7th year, the fee becomes RMB2000 ($328) and then increases to RMB4000 ($657) from the 10th to 12th year, RMB6000 ($985) from the 13th to 15 year, and RMB8000 ($1313) for the remaining years. The increased renewal fees assume that a patent maintained for more years shall be of higher commercial value given higher cost for longer renewal. If the required fee is not paid when the grace period (the first 12 months after the regular due date) passes, the patent lapses forever.

2.2. China's innovation strategy and the patent boom

China always sets specific goals for its innovation policies. Significantly, in 2002 China initiated three major strategies on talents, patents, and technical standards to strengthen indigenous innovation capability. The Medium and Long-Term Plan for S&T Development (2006–2020) (MLP) released in 2006 clearly stipulates achieving its annual domestic invention grants rank among the top five in the world by 2020. In 2008, China issued the Outline of National Intellectual Property Strategy. A corresponding National Patent Development Strategy (2011–2020), published in 2011 by SIPO, projects that China's annual patent filings by 2015 will approach 2 million and annual grants to domestic inventions will rank second in the world. Likewise, in China's 12th Five-Year Plan for the National S&T Development (2011–2015), a further target was proposed whereby the invention patent per ten thousand residents and per one hundred scientists will increase respectively from 1.7 and 10 in 2010 to 3.3 and 12 in 2015. Certainly, China will continue to come up with new targets until it becomes a leader in the world's patent landscape (Suttmeier and Yao, 2011).

The constant improvement of the patent system in China, mentioned above, has led to accelerating patenting activities to fulfill various goals set by the government. From 1985 to the end of 2010, SIPO had received 7,055,584 patent applications with an average annual growth rate of 19.5%, of which about one third are invention patents and over 6 million (or about 85.3% of the total) were from domestic applicants (Fig. 1). Patent filings have begun to surge after 2000, following the second amendment of the patent law. The annual filings finally exceeded the 1 million mark in 2010. As of December 2010, SIPO had approved 3,898,078 patents, of which only 18.5% were grants for inventions, 44.0% for utility models, and 37.5% for industrial designs.

2.3. The patent boom in the agriculture sector

Patent applications and grants in the agricultural sector show a similar pattern although they only account for 2.3% and 2.2% of the total respectively. Between 1985 and 2009, applications for agricultural innovation had enjoyed the average annual rate of 16.1%, resulting in an overall growth of applications by almost 35 folds. By the end of 2009 accumulative applications and grants for agricultural innovation reached 132,754 and 68,984 respectively.[3]

Strikingly, the number of domestic invention patent applications rose by approximately 69 folds between 1985 and 2009, while the foreign filings only increased by less than nine folds (Fig. 2). The year 2000 was the starting point for the boom of agricultural patenting activities as well. Since then, both domestic and foreign applications have shown an upward trend, but their patenting behaviors differ significantly with almost all foreign applications (more than 99%) registered as inventions whereas only slightly more than half of the domestic applications (57.2%) in the same category. Meanwhile, domestic inventions have grown at a more rapid pace and steadily outnumbered foreign applications lately. In 2007 and 2008, domestic invention applications exceeded foreign ones by a ratio of more than three to one. Obviously domestic entities have driven the patent boom in all sectors and the agriculture sector.

There are similar patterns of growth for domestic and foreign invention grants during the recent years (Fig. 3). Here a “fake” trend worthy of discussing is that the number of grants seems to have turned downward since 2005. This is simply because many of the recent applications had not been granted by the end of 2010. Nevertheless, the overall rising pattern has been intact. In addition to the year 2000, the year 1993 is another key point when the grants began to increase substantially, which might be attributed to the first patent amendment in 1992 that extended the scope of patent protection to chemical and biotechnology fields and made relevant agricultural innovations patentable. As a whole, the annual growth rate of the Chinese patents granted to domestic applicants averaged 19.2% between 1985 and 2005.

2.4. The patent boom by technologies and entities

Table 1 tabulates the number of invention patent applications filed by domestic and foreign entities in major technological fields of agriculture—agronomy and forestry, livestock, aquaculture, fertilizer, plant protection, and ag-biotech—in 1985, 1993, 2001 and 2005. Ag-biotech has played an important role in the agricultural patent applications, seeing the fastest

[3] We don't have complete data for 2010 because the majority of agriculture-related patent documents filed have not been published in the SIPO database, although SIPO has announced the compendium of statistics for the total number of patents in 2010.

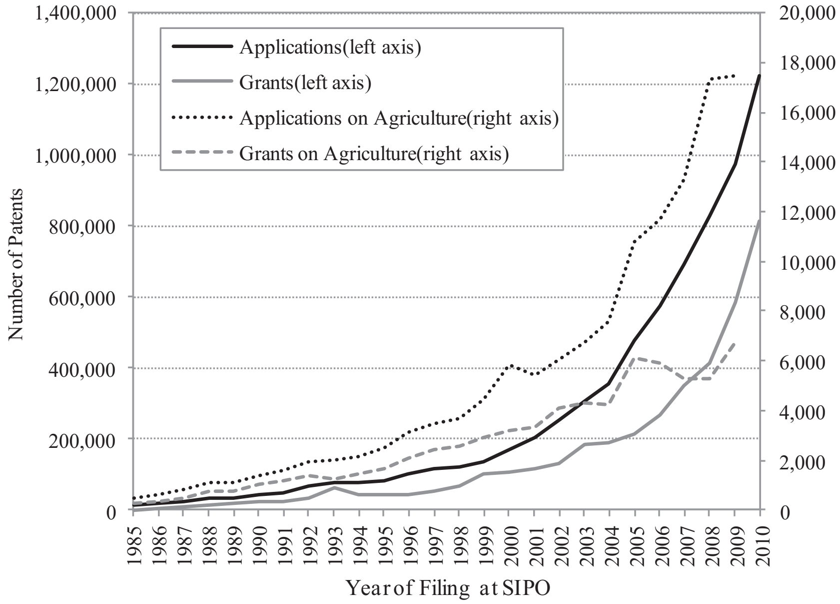

Fig. 1. Chinese patent applications, 1985–2010. Source: website of State Intellectual Property Office www.sipo.gov.cn.

growth with the annual growth rate of 20.7% and accounting for 44.2% of total agricultural applications between 1985 and 2005. Table 1 also contrasts the patenting activities of domestic and foreign entities, domestic public and private entities. From 1985 to 2005, foreign applicants had consistently focused on ag-biotech and plant protection, which are also the most profitable in agriculture. Domestic applicants filed more applications than foreigners in the fields of agronomy and forestry, livestock, aquaculture and fertilizer. On the one hand, the considerable increase in applications by domestic entities suggests a rise in China's indigenous innovation output in agriculture. And the great disparity in applications across technology fields also shows that domestic innovation capability is heterogeneous. On the other hand, the grant ratio of foreign applications is remarkably higher than that of domestic applications. For instance, in 2001 the average grant ratio of foreign applications is 52.4%, whereas domestic patent grant ratio is only 38.6%. However, the examination period is usually longer for foreign than domestic applications (Liegsalz and Wagner, 2013). For example, for patents filed in 2005, by 2009, 73.5% of foreign applications are still under substantive examination while only 13.7% of the domestic applications have not been processed completely. This explains why the grant ratio of foreign applications in 2005 is merely 11.0%, significantly lower than that of domestic applications. So far, although the average grant ratio of domestic applications is slightly greater than that of foreign applications (43.1% versus 42.6%), foreign entities may have filed more valuable applications than their domestic counterparts controlling variation of grant lags.

Domestically, applications from private entities slightly outnumbered those from public ones, although the grant ratios are reversed. The higher grant ratio for public entities means that their applications are more likely to meet the quality criteria set by SIPO, thus having higher value than

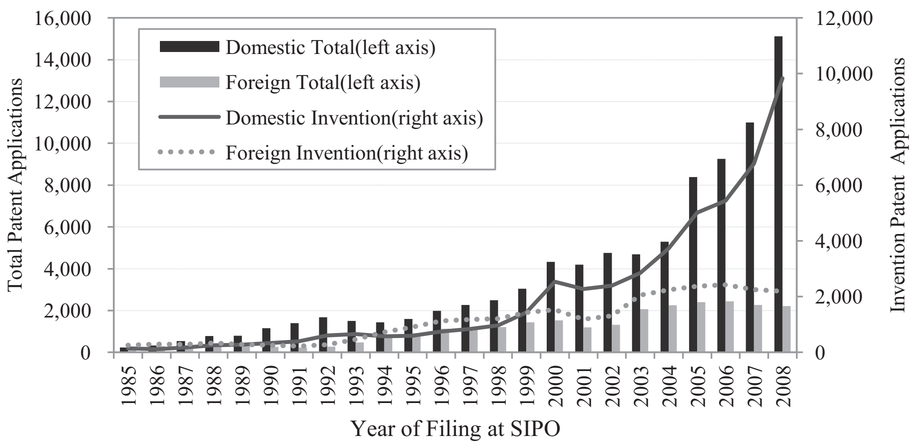

Fig. 2. Chinese patent applications in Agriculture, 1985–2009. Source: website of State Intellectual Property Office www.sipo.gov.cn.

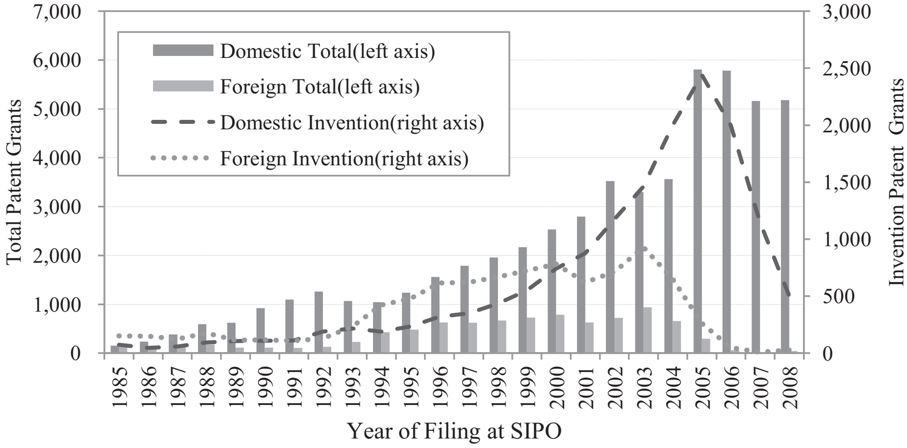

Fig. 3. Chinese patent grants in agriculture, 1986–2008. Source: Authors own collections from database of State Intellectual Property Office.

those from private entities. Moreover, the gap in grant ratios between public and private entities was enlarged from 16.4% in 1985 to 27.7% in 2001.

However, the ground of comparing grant ratios is not conceivable as grant ratio doesn't control the effect of filing strategies. In the case of recent applications, many of more complex patents (e.g. with substantial claims or specification pages) take longer in the course of examination proceedings and have not been granted, and only small portions of relative simple patents have been processed. Thus, the grant ratio may not fully reflect the distribution of economic value.

3. Literature review and research questions

3.1. Patent value and measurement

Patent value is different from patent quality although they are highly related. Patent quality in this study is defined as a measure of how well the patent conforms to the statutory requirements for validity in the patent law. If a patent is granted, its quality should be fixed and stable because it is not allowed for revision thereafter. Patent value, like value of any other property, however, may fluctuate over time, as markets change. In particular, "patent value" means two things. On the one hand, a patent is endowed with "technological value" or "social value" if it passes the statutory requirements for a grant. On the other hand, a patent has "business value" or "private value" as it could be used (for new products, processes or licensed) or strategically possessed (for blocking other firms' technologies). We will focus on and analyze the value of agricultural patents on the second meaning (Suzuki, 2011), following the practice in most of the existing research.

As it is rather difficult to directly measure patent value, empirically, a number of proxies are introduced. Thus, patent value can be assessed through the patent statistics approach, the market value approach, and the survey-based approach (van Zeebroeck, 2010). The patent statistics approach concludes that patent value is positively correlated with patent citations, claims, family size and renewals (Harhoff et al., 2003; Schankerman, 2004). Of all the indicators, the analysis of patent citations is most promising. Generally, the more a patent is cited, the higher its value, because if more firms continue to invest on developing innovation disclosed in a previous patent, then the citing patent presumably signals that the cited patent must be of great technological importance and business value (Hall et al., 2005). The number of independent claims is deemed as another important indicator of patent value, as patents with more claims should incur a higher filing fee. The more claims a patent lays out, the more exclusive opportunities the patentee would possess (Moore, 2004; Hikkerova et al., 2013). As an indicator seeking protection in a geographical scope, the patent family size also represents the market value of patent rights. The size of a patent family, particularly the number of international patent filings with the same priority patent, reflects the efforts and cost incurred by patentees to protect their rights within a broader geography (Harhoff et al., 2003; Griliches, 1990). The majority of research on patent value uses such patent families as the triadic patent data published by OECD (Sternitzke, 2009). Then, after a patent has been granted, the duration of its rights can be used to measure its private value as well (Schankerman and Pakes, 1986). In most countries, patentees must pay an annual renewal fee to keep their patents in force. Generally, if the expected benefit of a patent is less than the annual renewal fee, the patentee will stop paying to let the patent lapse. Therefore, a more valuable patent is presumably to be maintained for a longer period at the expense of renewal fee. It is broadly acknowledged that the number of years a patent is renewed and the number of countries in which protection for the same invention is sought can be employed to measure the potential value of patent rights (Lanjouw et al., 1998). For example, the scope-year index, combining the two dimensions of patent families and renewals, has been developed to measure the patent value with the large sample from EPO (van Pottelsberghe de la Potterie and van Zeebroeck, 2008). In addition, opposition from rival firms has been found to be positively related to a patent's value (Harhoff et al., 2003). The market value approach investigates the correlation between different features of patents and firm's market value or performance, and then estimates the value of patents accordingly (Hall et al., 2005; Griliches, 1981; Hsieh,

Table 1
Agricultural invention patents filed by domestic and foreign entities.

Fields	1985				1993				2001				2005				1985–2005			
	Domestic			Foreign	Domestic			Foreign	Domestic			Foreign	Domestic			Foreign	Domestic			Foreign
	All	Public	Private		All	Public	Private		All	Public	Private		All	Public	Private		All	Public	Private	
Agronomy and forestry	46	17	26	30	108	33	63	21	289	85	181	76	956	394	467	155	4991	1769	2788	1223
	(32.6)	(35.3)	(26.9)	(56.7)	(39.8)	(66.7)	(30.2)	(61.9)	(43.9)	(64.7)	(35.9)	(56.6)	(43.8)	(60.9)	(29.3)	(30.3)	(45.5)	(65.4)	(35.2)	(57.9)
Livestock	15	5	8	19	77	17	51	17	172	24	136	61	442	131	276	125	2481	611	1637	948
	(46.7)	(60.0)	(37.5)	(52.6)	(28.6)	(41.2)	(25.5)	(70.6)	(37.8)	(66.7)	(32.4)	(67.2)	(41.0)	(62.6)	(31.5)	(12.0)	(41.6)	(57.9)	(37.3)	(48.5)
Aquaculture	4	1	3	2	20		19	9	34	9	24	52	124	58	54	61	677	218	410	559
	(25.0)	(0.0)	(33.3)	(50.0)	(30.0)		(26.3)	(22.2)	(44.1)	(44.4)	(41.7)	(76.9)	(50.0)	(56.9)	(37.0)	(23.0)	(45.5)	(61.0)	(38.3)	(60.3)
Fertilizer	15	9	4	7	94	22	63	5	167	28	115	17	345	85	211	26	2655	575	1717	235
	(73.3)	(77.8)	(75.0)	(42.9)	(31.9)	(36.4)	(31.7)	(40.0)	(31.7)	(53.6)	(27.0)	(70.6)	(51.6)	(75.3)	(45.5)	(30.8)	(38.8)	(57.9)	(33.8)	(48.1)
Plant protection	34	30	4	141	217	66	123	280	432	96	263	342	899	354	459	529	5828	1858	3282	5912
	(58.8)	(60.0)	(50.0)	(60.3)	(33.2)	(47.0)	(21.7)	(52.5)	(41.0)	(57.3)	(33.5)	(56.4)	(49.2)	(63.3)	(39.0)	(17.2)	(42.1)	(58.4)	(33.9)	(47.9)
Ag-biotech	32	25	4	56	138	65	55	137	1177	464	573	637	2244	1496	508	1481	9959	4897	3905	10,604
	(59.4)	(56.0)	(75.0)	(64.3)	(32.6)	(41.5)	(27.3)	(40.1)	(37.3)	(54.5)	(23.2)	(45.8)	(51.6)	(57.6)	(39.6)	(5.9)	(43.8)	(59.2)	(26.8)	(36.3)
Total	146	87	49	255	654	203	374	469	2271	707	1292	1185	5010	2518	1975	2377	26,591	9928	13,739	19,841
	(50.0)	(55.2)	(38.8)	(59.6)	(33.3)	(46.8)	(26.2)	(49.3)	(38.6)	(56.4)	(28.7)	(52.4)	(48.7)	(59.8)	(36.5)	(11.0)	(43.1)	(60.1)	(32.6)	(42.6)

Source: Authors' own calculations using the SIPO database. The field is classified on the basis of international patent classification (IPC) taxonomy. Universities and research institutes are categorized as public applicants, while companies and individuals as private applicants.
Notes: Grant ratios are reported in parentheses. Grant ratio (%) in 2008 is not available because many of applications are under processing. Patents filed jointly by domestic public and private entities accounts for only 8.70% of the domestic applications, and their details are not reported.

2013). Finally, the survey-based approach relies on the subjective responses of inventors or owners to examine the value or importance of their inventions (Gambardella et al., 2008; Giuri et al., 2007).

Constrained by the individual patent data available for Chinese patents, we will only use the patent statistics approach in this study to track the changing value of China's agricultural patents. Specifically, our research focuses on patent renewal of Chinese agricultural patents. We do not adopt other patent value indicators such as citations, claims and family size, because the citations and claims of Chinese patents are simply missing in the SIPO database and their family size is not only very small but also almost homogenous. Chinese applicants largely file patents only within China and 95% of its patents are domestically oriented (Huang, 2010). As a Royal Society study shows, compared with world-leading countries such as Japan, Chinese international patent applications are still very few. China just registered 1655 patents in the US Patent and Trademark Office (USPTO) in 2009 compared with Japan's 35,501. Indeed, except for a couple of telecommunication companies such as Huawei and ZTE, most of the Chinese firms do not register patents abroad (Wilsdon et al., 2011). Therefore, the patent family size is not an appropriate indicator for the analysis of Chinese patent value, at least for the time being. Finally, we will analyze the patent renewal indicator, as it at least reflects a patentee's expectation for the value of the patent.

3.2. Formulation of research questions

Our analysis will shed new lights on the value of China's patenting activities and in turn the improvement, or lack thereof, in innovation capability by using patents as a measure. Toward this end, we will address four research questions to explore how the value of Chinese agricultural patents has changed amid the patent application boom and speculate the trajectory of innovation in China.

The first question underlines our foremost concern, that is, whether value of agricultural patents has improved over time (Q1). There have been concerns that the average value of Chinese patents might be decreasing during the patent boom, as what has been observed in Europe and the United States (Archontopoulos et al., 2007; Buccola and Xia, 2004; OECD Science, 2011). One of the most prominent arguments is that patent quality criteria (especially the basic substantive requirements) are easily compromised because the number of patent examiners usually cannot keep pace with their increased workload because of the rising number and complexity of applications (Hall, 2007). However, unless there is evidence that the bar set for assessing the quality of applications has been lowered, one cannot conclude a decline in quality of grants at the expense of the increase in quantity (Li, 2012). As we present in Section 2.1, through revising the patent law, SIPO has raised the criteria for patentability. It is irrational to approve a large number of low-quality filings with lower potential economic value. Conversely, we have found that the average grant ratio of domestic applications has been improved in recent years. So we want to examine the changing value of Chinese agricultural patents via the first question (Q1) against the identical arguments raised by existing literature (Zhou and Stembridge, 2010; Li, 2012).

The second question concerns whether there is difference in the value of agricultural patents applied by foreign and domestic entities (Q2). For most of the technology fields, sharp difference does exist in the mean value of patents across nationalities (Schankerman, 1998), and on average the value of foreign patents is usually expected to be higher than that of domestic ones (Basberg, 1987; Beaudry and Schiffauerova, 2011). Foreign patents should be valuable, because they, compared with domestic entities filing patents at home, must pay extra cost (additional patent office fees, translation cost, attorney fees, etc.) to file a patent abroad, and the expected revenue must outweigh at least such additional cost (Dernis and Khan, 2004). Foreign patents filed with China's SIPO are primarily for inventions, whereas the majority of Chinese domestic patents, until most recently, consisted of utility models and design patents (Sun, 2003). Intuitively, therefore, the value of domestic patents might be lower than that of foreign ones. Such significant gap in economic value between foreign and domestic patents has been found using the 1985–1989 invention patent data. In particular, the median value of invention patents filed by foreign firms is 18 times higher than that of patents by domestic firms (Huang, 2012). And we would like to further compare the difference of patent value between foreign and domestic applicants by using more recent data that reflect the patent boom.

Moreover, whether the value of patents varies across domestic applicants has not been investigated. There are reasons to believe that a given patent is not equally valuable to different patentees. First, some patentees are better than others in protecting their intellectual property rights. Second, the value of a patent is a function of its patentee's patent portfolio and complementary mechanisms of appropriability (Sun, 2003). Chinese universities and public research institutes constantly dominate the patenting activities in agriculture. Recently, more private companies have realized the importance of intellectual property rights in their competition with foreign-invested firms and increased the propensity to patent, especially incentivized to own more patents with greater economic value. In the United States, it has been shown, the patent surge is clearly associated with an overall increase in university patents, but there was no increase in the number of “very important patents with high value,” probably because many universities with little experience and expertise have entered the patent system (Henderson et al., 1998). Therefore, our third research question (Q3) is whether the value of patents filed by public applicants thus far is higher than that of private applicants and if so, whether this phenomenon will change in the near future. Finally, we are interested in the distribution of patent value by technology areas. Most studies emphasize the significant difference of patent value across technology areas, because patents are not equally effective as mechanisms of appropriability across technologies. There is strong empirical evidence showing these differences. For example, the distribution of patent value in France varies sharply across technologies (Schankerman, 1998). However, this disparity disappears in technology fields where markets for technology licensing or sale work particularly well (Bessen, 2008). Thus we attempt to examine how patent value varies across technological fields and whether emerging fields such as ag-biotech shows advantages vis-à-vis conventional technologies (Q4).

In order to answer the four questions, we intensively explore how the value of recent agricultural grants has evolved alongside the fast growing quantity by using the patent renewal data. We will empirically compare the difference of patent value between domestic and foreign applicants, between public and private applicants, and across technological fields.

4. Method

4.1. Research design

Patents renewed for a longer period must be more valuable (van Pottelsberghe de la Potterie and van Zeebroeck, 2008; Schankerman and Pakes, 1986; Lanjouw et al., 1998; Schankerman, 1998). The longer period of protection a patent is maintained, the higher fee the patentee is to be charged for, as renewal fee not only is paid annually but also increases over years. Under the most favorable condition, a patent will be maintained until the full term expires. If a patent holder fails to pay the renewal fees in 1 year, the patent will irreversibly lapse and fall into the public domain. And the failure probability is commonly changing with increasing cost and uncertain factors such as potential income. Therefore, the renewal record of a patent is a clear indicator of how valuable the patent is to its holder. As discussed in literature review, the patent value is hard to measure directly, so here we use patent renewal data available at SIPO as a proxy to measure the value of Chinese patents at different points in times and fields. Other patent value indicators such as citations, claims and family size are neither adopted nor controlled in the modeling, simply because the information has not been disclosed by the SIPO database.

The timing features of patent death (the term "die" means lapse or expire) lead directly to the consideration of duration analysis in the study of patent renewal. Duration analysis is appropriate for events that occur at different times, because probability of the events may be changing over time and observations are censored (Ravenscraft and Scherer, 1991; Kleinbaum and Klein, 2011). The patent renewal record completely reflects how long patent rights survive before the event of death occurs.

Mathematically, we begin by defining $f(t)$ as a continuous probability density function of a random variable T, where t, denoted as a realization of T, is the length of a spell. Then a cumulative distribution function, $F(t)$ is given by

$$F(t) = \int_0^t f(\mu)d(\mu) = \Pr(T \leq t) \tag{1}$$

Equivalently, the distribution function of random variable T can be expressed by

$$S(t) = 1 - F(t) = \Pr(T > t) \tag{2}$$

In studying the duration of patent renewal (van Zeebroeck, 2007; Harhoff and Wagner, 2009; Liegsalz and Wagner, 2013; Nikzad, 2011), the survival function is usually written like Eq. (2). Where $S(t)$ gives the probability that a patent will have survived beyond t years from the date of filing without invalidation (lapse or expiration). Initially, $t = 0$ and $S(0) = 1$, indicating all patents are surviving. As time passes, the probability that a patent survives must decrease as the renewal cost increases. Hence, $S(t)$ shall be a strictly decreasing function.

Rather than focusing explicitly on the length of duration, our empirical analysis uses the survival model to examine the probability that a patent continues to be renewed and to observe how the survival probability changes over time and fields. We model this probability as a hazard function that depends upon patent's characteristics such as the affiliations of patentees, inventors, IPC codes, the year of filing, and others. The hazard function, denoted $\lambda(t)$, is defined as the event rate at time t conditional on survival until time t or later (that is, $T \geq t$):

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{\Pr(t \leq T < t + \Delta t | T \geq t)}{\Delta t} = \lim_{\Delta t \to 0} \frac{F(t + \Delta t) - F(t)}{\Delta s(t)} = \frac{f(t)}{S(t)} \tag{3}$$

Instead of measuring the span of patent life, we are interested in the probability of its "death," that is, the probability in which the patent lapsed from not paying maintenance fees or expired at full term. So we introduce explanatory variables in a linear model where the hazard rate $\lambda(t_i)$ for observation i is given by

$$\lambda(t_i) = \exp\left(\lambda_0(t) + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_j x_{ij}\right) \tag{4}$$

x_{ij} are time independent covariates, $e^{\lambda_0(t)}$ is defined as a baseline hazard rate, and $h_0(t)$ should be specified when all covariates equal zero. Therefore, the final model is as follows:

$$\lambda(t_i) = h_0(t) \exp\left(\beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_j x_{ij}\right) \tag{5}$$

We prefer to utilize the popular mathematical method "Cox proportional hazard (CPH)" to estimate the Eq. (5). The CPH model is very robust because it closely approximates correct parametric model. We also consider other parametric models to make sure of a correct model (e.g. Weibull, log-normal) by assessing the goodness of fit (Kleinbaum and Klein, 2011).

We will estimate the probability of patents surviving through the duration analysis of a patent surviving from filing date to lapse (patent life span) or to be maintained between the granted date and the "death" date (the length of patent renewal).

4.2. Data

The data for the study are composed of all agriculture-related invention patent applications filed at SIPO, China's patent office, between 1985 and 2005 with rights having been granted by the end of 2010. They were obtained from the SIPO database with the support of the Chinese patent tool "HIT software." The criteria for patent search and classification are based on the IPC system (the Eighth Version). We have mainly selected the agricultural patents from the subsectors A01 (agriculture; forestry; animal husbandry; hunting; trapping; fishing) and C12 (genetic engineering), and other agriculture-related classifications.[4]

After excluding some patents falling into the scopes of human, medical and industrial usage, we categorized the remaining patents into one of the six groups—agronomy and forestry, livestock, aquaculture, fertilizer, plant protection and ag-biotech.[5] For each patent we obtained all bibliographic information and dates indicating its legal status including filing, publication, entry into substantive examination, rejection, withdrawal, grant, lapse or expiration, transfer or license. From April 1, 1985 to the end of 2010, SIPO granted a total of 23,428 agricultural invention patents. As many of the patents filed after January 2006 are still under examination and only small portion of grants have been made, we only included the patents filed by the end of 2005 in the estimation, which number 17,801 grants.

4.3. Variables

Table 2 describes the variables used in the estimations. Durations—span of patent and renewal of patent—will be used as dependent variables with year dummies and field dummies expected to respectively capture the overall trend of patent value, which will be used to address Q1 and Q4. Modeling also considers time-invariant independent variables, representing patent characteristics. Particularly, nationality of applicants is used to answer Q2, and applicant types (public, company and individual) are suitable for identifying Q3. Universities and public research institutes are assigned into the same group "public" as the reference, as the survival of patents applied for by these applicants are almost identical. Additionally, patent breadth, priority claim and number of inventors are used to control the effect of filing characteristics on patent value. For example, Lerner (Lerner, 1994) introduced the total number of different 4-digit IPC-categories a patent was assigned to measure the patent breadth, and found that broader patents (i.e. applicable in more technological fields) tend to be more valuable than other patents.

Table 2
Variables used in estimations.

Name	Type of variables	Definition
Span of patent	DV	Number of patent years starting from the filing date to the end date
Renewal of patent	DV	Number of patent years starting from the granted date to the end date
Foreign	IV	1 = the patent was filed by foreign entity; 0 = otherwise*
Company	IV	1 = the patent holder is a private company; 0 = otherwise
Individual	IV	1 = the patent holder is an individual; 0 = otherwise
Year dummies	IV	Y2001,Y2002,Y2003,Y2004,y2005 = 1 when the filing year is 2001, 2002, 2003, 2004, 2005 respectively.
Field dummies	IV	Agronomy and forestry; Livestock; Aquaculture; Fertilizer; Plant Protection; Ag-biotech = technology field dummies
Breadth	CV	The number of four digit international patent classes (IPC) to which the patent was assigned.
Number of Inventors	CV	The number of inventor's name appeared in the granted publication
Priority	CV	1 = the patent has been claimed the priority right; 0 = otherwise

Notes: * Given that Taiwan just files a few patents on agriculture in mainland China, we exclude them from the final sample. DV–Dependent variable, IV–Independent variable, CV–Control variable.

5. Results

5.1. Preliminary analysis

Descriptive statistics for key explanatory variables shows that the average life span of all patents in agriculture between 1985 and 2005 is roughly 9 years, less than half of the patent's protection period, which is 20 years (Table 3). In particular, the average life span of foreign agricultural invention patents is 11.2 years, which is significantly longer than that of domestic patents, which is only about 7.5 years. The average length of patent renewal is about 4 years with foreign patents maintained around 1 year longer than domestic ones. The mean differences in both life span and renewal between foreign and domestic applications are significant at the 0.001 level. Furthermore, the survival of patents filed by different applicants (graph (a) and graph (b) of Fig. 4) shows that the survival curves for the foreign inventors are consistently located above those for the domestic ones in both life span and renewal, which seems to indicate that foreign patents survived longer than domestic ones. Remarkably, with a longer duration, applications from foreign entities also tended to have higher value than domestic applications on the average level, so the answer to Q2 is probably positive. The results of previous measurement on grant ratios is in line with the perception, but its temporal and dynamic trend on patent value needs further verification by survival analysis.

In addition, while 89% of the foreign applications came from companies, domestic companies only filed about 15% of the agricultural invention patents. In recent years, applications from domestic private entities have risen sharply and exceeded those from domestic public entities. This indicates that domestic private entities increasingly attach importance to managing innovation through patenting. Moreover, not only do their patents have longer life span, private entities—companies and individuals—also have been more sensible than public entities in renewing their patents. The difference between the means of patent maintenance by two types of entities is relatively small but highly significant. Patents from companies lived longest among the domestic

[4] The IPC coverage is described in the following search queries: A01, A21, A22, A23, A47C9/04, A61D**, B09C**, B05B, C05, C07, C07H 21/**, C07K 14/**, C12 (excluding C12L, C12N 5/08, C12N5/22, C12N5/28, C12N15/07), C13, G01N33/02, G01N33/03, G01N33/04, G01N33/06, G01N33/08, G01N33/10, G01N33/12, G01N33/14, G01N33/53*, G01N33/54*, G01N33/55*, G01N33/56*, G01N33/571, G01N33/573, G01N33/574, G01N33/576, G01N33/577.

[5] The details of classifying agricultural patents into subgroups are not elaborated here but are available from the authors upon request.

Table 3
Descriptive statistics of key variables.

Name	ALL	Applicant		Domestic Applicant		
	(N = 17,801)	Domestic (N = 10,168)	Foreign (N = 7633)	Pubic (N = 5900)	Company (N = 1540)	Individual (N = 2728)
Span of patent	9.09	7.51	11.20***	7.23	7.81***	7.97***
	(3.51)	(2.52)	(3.54)	(2.44)	(2.35)	(2.70)
Renewal of patent	4.07	3.64	4.63***	3.48	3.89***	3.86***
	(2.60)	(2.24)	(2.92)	(2.13)	(2.18)	(2.49)
Company	0.47	0.15	0.89			
	(0.50)	(0.36)	(0.31)			
Individual	0.17	0.27	0.04			
	(0.38)	(0.44)	(0.20)			
Foreign	0.43					
	(0.49)					
Breadth	2.67	2.24	3.25***	2.43	2.29***	1.82***
	(2.16)	(1.61)	(2.63)	(1.77)	(1.57)	(1.13)
Number of inventors	3.28	3.26	3.31	3.98	3.30***	1.68***
	(2.29)	(2.24)	(2.34)	(2.16)	(2.13)	(1.61)
Priority	0.57	0.02	1.31***	0.02	0.04***	0.02
	(0.87)	(0.16)	(0.88)	(0.16)	(0.20)	(0.15)

Notes: Standard deviations are reported in parentheses. *,** and *** indicate that the means are significantly different at the 10%, 5%, 1% levels respectively.

applicants, and the survival functions for public entities and individuals are somewhat close together at most points (Fig. 4(c) and (d)). It apparently disapproves Q3, which may be perceived true through comparing grant ratios. And we will further test statistical significance of whose—public or private—patents have higher value and especially how the value has been changing by calculating survival probability. But suffice it to say that at this point we are unable to reach a

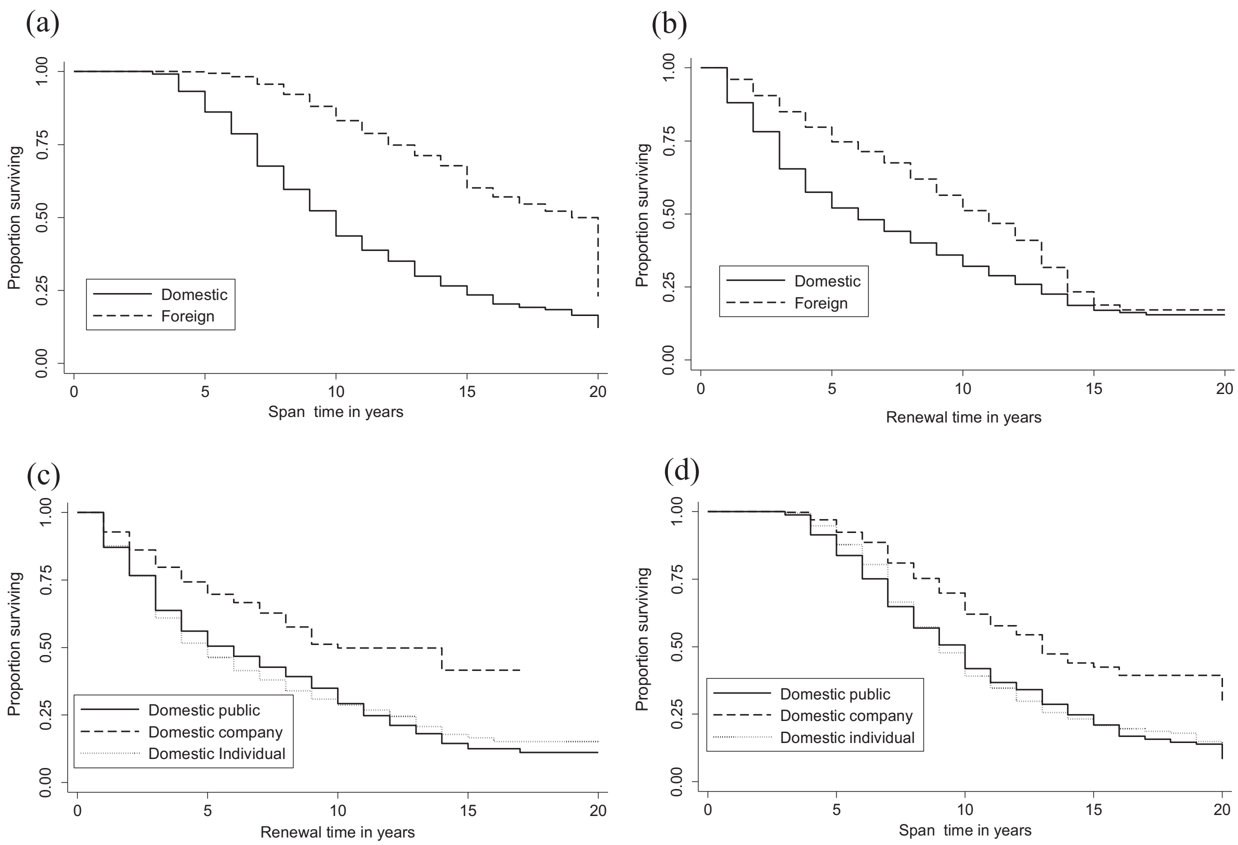

Fig. 4. Comparing the patent duration by Kaplan–Meier estimates.

definitive conclusion because the changing time and events make the descriptive analysis less robust.[6]

5.2. Empirical evidence

5.2.1. Modeling strategy

We supposed that the risk that a patent's lapse is increasing over time and specified a Weibull distribution function that accounts for such relationship, as noted in Section 4. First, we used parametric methods to estimate the duration model. Then we attempted to apply the CPH model to specify the model again. Last we compared the results from both models.

During the modeling process, we found that both Weibull and CPH estimates are nearly identical, but the Akaike information criterion (AIC)[7] given by the CPH estimation (115,410.1) is excessively larger than that of the Weibull estimation (19,536). Based on the AIC minimization criterion, the preferred model for our patent life span data is the Weibull model. Previous studies usually applied the CPH model to estimate the patent renewal data because it can be extended in several ways to assess the importance of various covariates in the survival time, and it is the most commonly used in survival analysis (van Zeebroeck, 2007; Harhoff and Wagner, 2009; Liegsalz and Wagner, 2013; Nikzad, 2011). We performed both CPH and parametric models, and finally selected the CPH model as the “best” model based on the change of the goodness-of-fit. We also estimated both the domestic group and foreign group using the same modeling strategy.

5.2.2. Estimation results

The results of the estimation are presented in Table 4. Measured by the likelihood ratio (LR) test, the overall models are statistically significant at the 0.001 level. For most of the covariates, the coefficient estimates are very high and significantly different from zero. To facilitate the explanation, we expressed coefficients in the form of hazard ratios. As each of the coefficients is less than one, the hazard rate of a patent's lapse is decreasing, hence the time-to-survival is increasing. By contrast, a greater-than-one hazard ratio implies that the risk is increasing with covariates while a hazard ratio close to one implies that the hazard rate is essentially invariant to changes to the covariates.

In Table 4, columns (1), (2) and (3) show results for the life span of patent using the Weibull estimations, with their shape parameters being 2.82, 2.65 and 3.22 respectively. With the test statistics $z = (p–1)/s.e.(p)$, the corresponding Z value being 62.38, 50.23 and 37.33, obviously the p value is significantly greater than one. Therefore the hazard rate of lapsing is monotonically increasing with time passing. It strongly confirms our previous theoretical assumption that the risk of patent lapsing is going up with time, which is understandable and expected.

5.2.2.1. Answering Q1. In order to examine the changing pattern of patent value, 5 year dummy variables were constructed to contrast patents filed before and amid the patent boom. For the overall sample, the estimated coefficients for year dummy variables in column (1) are close to one and not statistically significant except for the years 2002 and 2003. The patents filed after 2001 (the start of the patent boom period) don't survive shorter than those of patents filed before the boom, but the results cannot definitely disapprove Q1. Focusing on the domestic group, column (2) indicates that the duration of patents filed in 2002 and 2003 runs little shorter than that of patents filed in previous years. Specifically, the corresponding lapsing hazards for the patents filed in 2002 and 2003 are about 20% and 25% higher than those filed before 2001. Can we thus infer that domestic patents show a decreasing lifetime? Such a conclusion contradicts Q1 and needs to be examined further.

In order to seek further evidence to answer Q1, we conducted the following analysis that focused on the estimation of renewal probability. The reason for doing this is that applicants are supposed to pay maintenance fees only after a patent is granted, and therefore renewal length can disclose more information on patent value than life span. From the estimations for renewal data, we can find that all year dummy variables have statistically significant negative coefficients, which indicates that patents filed after 2001 are likely to be maintained longer than those filed before 2001. The signs and magnitudes of coefficients in column (4) show that for the overall sample the risks of lapsing among the recent filings decreased from about 60% for the 2001 grants to only 30% for the 2005 grants. Obviously patents filed in more recent years tend to be still maintained compared to those filed in earlier years. These figures convincingly answer Q1, that is, the value of Chinese agricultural patents has indeed improved over time. The estimates of maintenance period using the CPH models give further evidence than that of the life span. This pattern seems to be certainly present in both the domestic and foreign samples. Amazingly, for domestic grants the coefficients for year dummies in column (5) carry completely opposite signs compared to their counterparts in column (2). We should point out that such a difference is due to remarkable decrease of grant lag between 2001 and 2005. In particular, grant lag is equal to span of patent in column (2) minus renewal of patent in column (5). As noted briefly, the renewal length is a more suitable indicator of patent value than the patent life span. Thus the estimated coefficients of column (5) are believed to provide answers to Q1, suggesting that the domestic grants filed more recently tend to be maintained longer than those filed earlier. Specifically, the probabilities for the renewal of domestic grants filed in 2001, 2002, 2003, 2004 and 2005 are 34%, 39%, 45%, 60% and 70%, all significantly higher than that for patents filed in the reference period. We could deduce from the hazard ratios that domestic grants tend to be renewed with a longer period. In addition, a comparison of magnitudes of coefficients in columns (5) and (6) also confirms that the patent value (both the domestic and foreign grants) has been going up alongside the recent patent boom.

[6] As for other variables, compared with high propensity that foreign patentees seek priories, quite few domestic patents (merely 2.1%) claim the right of priority. The details of remaining control variables are not mentioned here and are available from the authors upon request.

[7] To assess the fit of nonnested models, the AIC is commonly computed for different models with comparable sets of covariates. $AIC = -2(\log L) + 2(C + P + 1)$, where L denotes the log-likelihood for the model, C denotes the number of covariates in the model and P denotes the number of structural parameters for the model.

Table 4
Econometric estimations of patent lifetime.

Models Variables	Span of patent (Weibull)			Renewal of patent (CPH)		
	All (1)	Domestic (2)	Foreign (3)	All (4)	Domestic(5)	Foreign(6)
Company	0.60***	0.49***		0.63***	0.53***	
	(−12.80)	(−13.37)		(−11.46)	(−11.96)	
Individual	0.77***	0.74***		0.81***	0.79***	
	(−7.41)	(−7.86)		(−5.92)	(−6.25)	
Breadth	0.95***	0.90***	0.97**	0.96***	0.92***	0.97***
	(−6.71)	(−7.81)	(−2.59)	(−5.47)	(−6.38)	(−3.09)
Number of inventors	0.98***	0.97***	0.99	0.99**	0.97***	0.99
	(−2.88)	(−4.20)	(−1.28)	(−2.24)	(−3.43)	(−1.25)
Priority	0.89***	0.50***	0.88***	0.93**	0.55***	0.89***
	(−4.45)	(−4.55)	(−4.77)	(−2.58)	(−3.84)	(−4.23)
Foreign	0.38***			0.59***		
	(−19.24)			(−10.46)		
Year dummies (the applications before patent boom as the reference group [1985–2000])						
Y2001	0.98	1.06	0.84	0.60***	0.66***	0.59***
	(−0.41)	(0.92)	(−1.30)	(−9.79)	(−7.13)	(−3.96)
Y2002	1.12**	1.20***	0.85	0.56***	0.61***	0.60***
	(2.31)	(3.42)	(−1.13)	(−11.95)	(−9.62)	(−3.56)
Y2003	1.16**	1.25***	0.76	0.51***	0.55***	0.57***
	(3.05)	(4.27)	(−1.66)	(−13.79)	(−11.63)	(−3.44)
Y2004	1.04	1.04	0.68	0.39***	0.40***	0.59**
	(0.77)	(0.74)	(−1.53)	(−17.83)	(−16.86)	(−2.12)
Y2005	0.94	0.91	0.43	0.30***	0.30***	0.55
	(−0.92)	(−1.48)	(−1.45)	(−20.25)	(−19.84)	(−1.03)
Technology field dummies (agronomy and forestry = reference group)						
Livestock	0.93	0.93 **	1.00	0.93	0.91*	0.98
	(−1.50)	(−1.33)	(0.02)	(−1.47)	(−1.64)	(−0.17)
Aquaculture	0.84 **	0.88	0.94	0.84**	0.91	0.95
	(−2.28)	(−1.39)	(−0.36)	(−2.28)	(−0.98)	(−0.33)
Fertilizer	0.80***	0.81 ***	0.96	0.83**	0.82***	0.98
	(−4.20)	(−3.69)	(−0.21)	(−3.52)	(−3.52)	(−0.08)
Plant protection	0.80 ***	0.72***	0.93	0.85***	0.75***	0.97
	(−6.02)	(−7.42)	(−0.86)	(−4.40)	(−6.69)	(−0.39)
Ag-biotech	0.62 ***	0.66***	0.67***	0.69***	0.69***	0.68***
	(−12.48)	(−9.26)	(−4.42)	(−9.76)	(−8.36)	(−4.28)
Shape parameter (p=)	2.82	2.65	3.22			
Subjects/observations	17,801	10,168	7633	17,801	10,168	7633
Failures	6525	4464	2061	6525	4464	2061
AIC	19,536	12,503.5	6804.50	117,615.7	76,467.13	33,174.16
Log likelihood	−9749.99	−6234.75	−3387.25	−58,791.85	−38,218.56	−16,574.08
LR chi2	3898.03	544.76	120.43	2038.92	1199.90	155.73

Notes: Z-statistics in parentheses. * significant at the 10% level; ** significant at the 5% level; * significant at the 1% level.

5.2.2.2. Answering Q2. Foreign grants probably sustain a longer period than domestic grants, as the coefficients for foreign dummy (foreign = 1) in column (1) and column (4) respectively indicate that the survival probability for foreign grants is 62% higher and the renewal probability for foreign grants is 41% higher than those for domestic grants respectively. These findings answer our second question (Q2) that is foreign grants would have a higher value than domestic grants.

5.2.2.3. Answering Q3. Regarding the effects of assignee characteristics (Q3), the coefficients in both column (1) and column (4) reveal that patents filed by the private sector (companies and individuals) are likely to sustain longer than those by the public sector (universities and research institutes). This is especially typical for domestic grants as we formulated Q3. As shown in column (2) and column (4), the survival probability and renewal probability for patents filed by companies are 51% and 47% respectively higher than those for patents by the public sector; so do patents from individual applicants. Hereby the answer to Q3 is as follows: patents filed by the private sector have been renewed longer than those by the public sector, although the comparison of grant ratios between domestic public and private applicants intuitively indicates otherwise. The result shows that with a stronger economic incentive driving patenting activities, the Chinese domestic private sector is more likely to keep patents alive than public entities as universities and public research institutes that are more likely to file a patent for the sake of meeting the performance evaluation requirement instead of protecting and more importantly transferring or using their innovation. We cannot draw similar difference for foreign grants given that applications filed by foreign public entities are extremely small relative to their private counterparts.

To further illustrate specific differences between domestic assignees, we use the CPH methods to model the renewal period for domestic public and private entities separately.

The results suggest that in recent years domestic universities and research institutes tend to maintain a longer renewal period than they did in the reference period (1985–2000) (Table 5). The lapsing risks for patents filed in the booming years decrease significantly and monotonically. For instance, the lapsing risk for patents filed in 2005 by research institutes is only 24% of the risk for the patents filed in the reference period. Patent grants to domestic private entities show a similar trend. The coefficients for year dummies in Table 5 also show that compared with universities and research institutes, companies and individuals are more likely to raise the survival probability for their grants, and companies have strikingly improved their patent renewal record with the most remarkable efforts. This finding confirms the result of grant ratios, shown in the descriptive analysis. That is, applications from domestic private entities might be of inferior quality, but once their applications granted by the patent office, they are prone to maintain their patents longer than their public counterparts. This phenomenon provides decisive support to the view that private entities' patenting activities are driven by economic incentives and most of their grants are used to gain the competitive advantage for marketing products. So Q3 is validated finally, or the perceived value of domestic public filings is not higher than that of domestic private ones.

5.2.2.4. Answering Q4. With regard to the effect of technology fields on patent value (Q4), all the estimated coefficients for field dummies are significant but negative. As it is apparent from column (4), compared with grants to inventions in agronomy and forestry, livestock and aquaculture, those in the fields of ag-biotech, plant protection and fertilizer probably have lower probabilities of lapsing. Especially the ag-biotech grants have the lowest hazard ratio, which represents only 69% of the failure risk compared with the renewal of agronomy and forestry grants. Apparently, complex and emerging inventions (such as agricultural chemicals, genetic engineering product and methods) are likely to be maintained longer. Variation in the value of domestic patents is consistent with their different patenting propensity across technological fields, which can be intuitively explained by the heterogeneity of potential market revenues generated by these technologies. However, interestingly, the foreign grants show no significant difference in the renewal period by technologies except for ag-biotech. This could be explained by the fact that foreign applicants would maintain all patents while domestic applicants appear to be selective, giving more preference to the grants in some specific fields (e.g. ag-biotech, plant protection). The results clearly respond to Q4: patent value varies significantly across technological fields with the ag-biotech patents showing an advantage over other technologies.

Synthesizing the above estimations, we conclude that domestic grants appear to have a better performance in the renewal length during the patent boom period, and the improvement in the renewal record varies significantly across patent assignees and technology fields. As for other controlling variables, the effects of patent drafting characteristics including patent breadth and number of inventors are statistically significant at the 0.01 level but almost negligible because their coefficients are close to zero. Another interesting result is the negative coefficients for the priority variable. It is widely recognized that patents with the priority right are usually associated with higher value (de Rassenfosse et al., 2013), and their inventors tend to maintain their grants longer. The effect

Table 5
Econometric estimations of renewal of domestic patent by assignee.

Variables	Public sector		Private sector	
	University (1)	Research institute (2)	Company (3)	Individual (4)
Breadth	0.90***	0.85***	0.91**	0.95**
	(−5.21)	(−7.33)	(−2.33)	(−2.10)
Number of inventors	1.00	0.94***	1.01	1.00
	(−0.33)	(−4.38)	(0.46)	(−0.17)
Priority	0.49*	0.59*	0.49*	0.59**
	(−1.91)	(−1.73)	(−1.83)	(−2.20)
	Year dummies (the applications before patent boom as the reference group [1985–2000])			
Y2001	0.79**	0.68***	0.45***	0.60***
	(−2.11)	(−3.68)	(−4.64)	(−4.81)
Y2002	0.70***	0.58***	0.35***	0.57***
	(−4.07)	(−5.06)	(−5.97)	(−5.76)
Y2003	0.67***	0.52***	0.40***	0.49***
	(−4.63)	(−6.33)	(−5.43)	(−7.26)
Y2004	0.41***	0.43***	0.19***	0.42***
	(−10.32)	(−7.83)	(−8.02)	(−7.66)
Y2005	0.33***	0.24***	0.07***	0.30***
	(−12.77)	(−9.54)	(−8.15)	(−8.64)
Subjects/observations	2921	2754	1540	2728
Failures	1319	1180	413	1435
AIC	19,465.11	17,085.27	5445.44	20,953.83
Log likelihood	−9724.55	−8534.63	−2714.72	−10,468.91
LR chi2	281.09	309.05	230.45	222.34

Notes: Z-statistics in parentheses. * Significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level.

of priority rights is remarkable on the domestic grants, as shown in columns (5). That is, the renewal probability of domestic grants with priority claims is 45% higher than that of those without priority claims.

6. Conclusions and discussions

6.1. Conclusions

Our empirical work attempts to assess the evolving pattern and the direction of patent value change in the agricultural sector amid China's patent boom. Motivated by these, we have specified four research questions respectively to unveil how the value of agricultural patents has changed (Q1), what has been the value difference between domestic and foreign patent applications (Q2), between domestic public and private patent applications (Q3), and across different technological fields (Q4). Given that patent renewal is seen as a key indicator of patent value in the innovation literature, using the patent's survival data (including the patent life span and renewal data) from the SIPO database, we have conducted duration analysis with the Weibull and CPH modeling respectively. The results show that as a whole Chinese agricultural patents' value, measured by the length of life span and maintenance period, has been improving amid the recent patent boom. Especially after 2001, the risk for a patent to lapse is much lower than that filed before 2001, which implies that inventors are prone to maintain their patents for a longer period because of their perceived higher commercial value. Confirming Q1, our findings reasonably suggest that there may be not a serious reduction in the value (quality) of Chinese domestic applications amid the patent boom.

The analysis also reveals that the value of foreign grants is significantly higher than that of domestic grants, as measured by both the patent life span and the length of patent renewal. Innovation in China's agricultural sector has been flourishing in recent years in terms of the numbers and the grant ratios of domestic invention patent applications. Domestic invention patents have already outnumbered foreign filings, and average grant ratio of domestic invention patents is also remarkably higher than that of foreign ones.[8] While the value of domestic invention patents is indeed trending upward, the estimations by survival analysis suggest that domestic grants are not as valuable as foreign grants. Moreover, as time goes by, foreign applicants tend to make significantly greater improvements in patent lifetime than domestic applicants, although recent domestic grants also appear to be renewed with a longer period than before. We can respond to Q2 very positively, because domestic entities don't make efforts to raise patent value like their foreign counterparts.

For domestic grants, it can be found that companies and individuals are likely to maintain patents longer than universities and research institutes. It is an amazing phenomenon as it completely disapproves our third question (Q3). The domestic public sector has filed nearly two thirds of the domestic applications. Nevertheless, since the late 1990s it is the applications from the domestic private sector that have risen sharply and exceeded those from the public sector. This indicates that domestic private entities are making great efforts to innovate and protect their intellectual property rights. Furthermore, private entities behave slightly better than public entities in maintaining both a patent's life span and renewal length. In particular, private entities are more likely to raise the survival probability for grants filed in the recent booming years. The survival analysis expands our understanding of who is doing better in agricultural innovation. Private entities might still have a lower grant ratio, but once their applications are granted, they are likely to maintain a longer protection period than public entities. It might be explained by the fact that patenting activities in the private sector are driven by economic incentives. Unfortunately, many applications from the public sector are filed solely for meeting academic performance assessment requirement of an inventor because nowadays Chinese universities and research institutes consider patents to be as important as publications. Once the relevant research evaluation completes, patent utilization and maintenance are neglected once and for all. Once again, the phenomenon indicates that the motives of patenting do lead to the difference of patent value (or quality) between the public and private entities.

In addition, the analysis of patents by technological fields and other characteristics is more revealing. Since 2000, the starting point for the boom of patenting activities, ag-biotech in the agricultural sector has seen the fastest growth in the value of the patents. Moreover, grants to complex and emerging inventions such as agricultural chemicals, genetic engineering products and methods survive longer. Exactly as Q4 describes, the value of patents varies significantly across technological fields. For both domestic public and private entities, the lapsing risks for ag-biotech are extremely smaller than those for other technologies.

6.2. Contributions and implications

China's patent boom has become a hot subject of extensive academic investigation. Prior studies have examined the driving forces behind the rapid growth in quantity but neglected the changing value of patents. Some recent research has looked into the patent quality (value) but embedded serious bias in the measurement because of the use of simple indicators such as ratios of granted invention patents. This study starts with the question whether the value of Chinese patents has declined amid the recent upsurge. By adopting the patent renewal as a proxy to measure patent value in the agriculture sector, our empirical analysis shows that the reduction in patent value didn't occur. Thus our study provides new evidence to challenging the concern as to whether the patent bubble is forming in China and complementing the existing work.

The results will offer important implications for both policy makers and practitioners in the arena of intellectual property and innovation management. First, it should be noted that recent patent boom has had something to do with the government's innovation policy, which provides various subsidy and tax reduction to patenting. Such incentives may distort the nature of patenting and give rise to a large number of low-quality patents that merely pass the threshold for

[8] But we should mention that many of the recent foreign filings via the route of Patent Cooperation Treaty are still under examination and only small portions of them have been granted. Thus, tracking the grant ratio alone cannot reflect the overall quality of applications.

patentability but lack high economic potential value. Although our analysis shows that patent filing surge has not led to a quick deterioration of the average value of Chinese patents, in order to reduce the possibility in the future, specific patent quality (value) requirements should be incorporated into patent incentive programs at both the national and local level. Second, domestic entities have made substantial contributions to accelerating the patent boom, which is considered an important indicator for increase in the output of its national innovation system. However, the average value of domestic grants still significantly lags behind that of foreign ones. Chinese patentees (especially firms) need to improve their patent filing strategy like their foreign counterparts. For example, claiming priorities, increasing patent breadth, and focusing on complex and emerging technologies. Third, as the difference across technology fields shows, the agriculture sector should shift patenting emphasis from traditional agronomy to emerging agricultural biotechnology with higher economic potentials. If many profitable and marketable inventions are filed, the average value of domestic grants may catch up to that of foreign ones. Therefore, rather than drawing a static picture of China's innovation in agriculture, our study points a clear trajectory that Chinese innovators could and should take in the future from the perspective of mobilizing and concentrating resources.

6.3. Limitations and recommendations

There are limitations to our work. First, we have not used other common measures of patent value, such as citations, claims and family size as control variables. Obviously they have been constrained by data availability. If SIPO replenishes more information, not only could future research include these variables in the modeling and assure the robustness of estimation results, but also scholars could have a more dynamic picture of innovation in China. Alternatively we can use a small fraction of Chinese patents, which are also filed in major foreign patent office such as the USPTO and the EPO, as a sample to study the evolution of patent value, because either the USPTO or the EPO commonly releases the information of value indicators missed in SIPO.

Second, our analysis excessively relies on patent data. Without linking this information to R&D statistics and survey of inventors, we are simply unable to examine the impact of R&D input, patent royalties and patent policy on the patent value. In fact, the lapse of a specific patent sometimes is probably due to an applicant's economic burden rather than just the patent's low value. There might be scenarios in which a patent with potential to be of high value may not be translated timely into any monetary revenue because of an immature technology market, and then later the applicant cannot afford the renewal fees and finally have to relinquish the patent. The neglect of patent revenue variables will probably confound the estimated trends of patent value. Therefore, the combination of patent statistics and the survey-based approach will be more suitable to measure patent value. Third, our analysis that focuses on the agriculture sector could be extended to the examination of patents in other sectors so as to further validate our findings.

With these caveats in mind, our study still represents an understanding of the change in Chinese agricultural patents' value behind recent explosive patenting activities. Future work should be extended to more industry sectors and include more patent value indicators as control variables in the modeling. Additionally, our study suggests how survival modeling could be used to monitor and forecast evolving patent value, which encourages future work along this line to the field of technology assessment and forecasting in general.

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