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Impact of Seed Regulation Reform on Licensing Fees of Varieties in China

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ABSTRACT

Crop breeding research and seed industry development are critical to promoting sustainable growth in agricultural production and ensuring food security. The Chinese government introduced a significant reform to the original seed regulation system, which was overly focused on market access management. This revision can profoundly impact the licensing market of seed varieties in China. However, the licensing issue in the seed industry has barely been tapped owing to the limited availability of real licensing data. This study aims to analyze the impacts of the seed regulation reform on the licensing fees of varieties in China based on some unique actual transaction data of variety licensing. We employed a nationwide in-person survey of seed companies and used a multivariate analysis. The results indicate that most seed companies in China were obliged to buy licenses for new varieties bred by others. An upfront lump-sum fixed-fee payment had also been the most used strategy for variety licensing. The estimation results of the multivariate analysis indicate that seed regulation reform in China led to an average decline of nearly half of the licensing fee of a variety. After the reform, the licensing prices of conventional rice varieties decreased the most, followed by maize varieties. By contrast, the reform did not significantly affect the licensing fees of hybrid rice varieties. The reform resulted in a 63% drop in licensing fee of a public-bred variety, while having no significant impact on that of private-bred varieties. Post reform, the licensee fee of a variety paid by smaller seed companies and non-state-owned enterprises (SOEs) decreased by 62% and 65%, respectively, while the fees paid by bigger seed companies and SOEs were not significantly affected. Moreover, the results confirm that newer varieties and the varieties with higher yield and exclusive contracts have significantly higher licensing fees, and large seed companies paid significantly more on a variety license. These results have important implications for market participants and policymakers in China's seed industry as well as other industries.

JEL Classification: O25, O32, Q16

1 | Introduction

Crop breeding research and seed industry development are critical in promoting sustainable growth in agricultural production and ensuring food security. Genetic advances in plant breeding have contributed half of the total yield gains of major field crops in the past century (Duvick 2004). The turnover of improved cultivars used by farmers is also influenced by variety release and seed industry policies (Smale et al. 2008).

Since the promulgation of the first Seed Law in 2000, China's seed market has transformed the monopoly operation of state-owned seed companies into joint competition by multiple market players (Hu et al. 2009). In 2000, the government passed the first seed law to legally define the role of the private sector, which opened the way for seed commercialization in China (Hu et al. 2011). Since then, China's seed industry has increasingly attracted private investment (Spielman and Kennedy 2016) and it is already the world's second-largest seed market after the United States. The commercial value of the national seed market has increased from 25 billion RMB in 2000 to 128 billion RMB in 2021 (Ministry of Agriculture and rural affairs of the People's Republic of China MARA 2022).

However, China's seed regulation system, established before seed commercialization, could not adapt to the new situation of increased private sector investment. As in other developing and industrialized countries, its system is historically for the public breeders (Tripp and Louwaars 1997). The Value in Cultivation and Use (VCU) system for varieties is the most important part of the policy. To ensure the quality of varieties used by farmers and national food security, the Chinese government began to establish a unified VCU system for varieties in the 1980s. Under this system, the variety could only be released or sold after it has passed the VCU test and been approved by official authorizations. The system covered 28 crops (almost all major crops in China), and the testing channels were quite limited (only unified national and provincial VCU testing) (Huang and Hu 2023). China's seed regulation system focused too much attention to market access management in the early stage and not enough on the supervision of the seed market in the later stage. This made it difficult to provide a friendly business environment for seed companies and reduced the incentives for private investment in plant breeding. In such a situation, commercial breeding in China relies heavily on the public, and many seed companies need new variety licenses from the public breeders (Huang and Hu 2023). In fact, China's seed market is mainly composed of a large number of small and medium-sized companies that lack the ability of independent breeding (Ministry of Agriculture and rural affairs of the People's Republic of China MARA 2022).

The Chinese government has been aware of these problems and revised the Seed Law at the end of 2015. This introduced significant reforms to the original seed regulation system, especially the VCU system. The new system covers only five main crops (i.e., rice, maize, wheat, soybean and cotton), while others can be released or sold as long as they are registered without the VCU testing. Even for the five main crops, the variety testing channel has been greatly expanded, and is not limited to the original unified national and provincial VCU testing. Enterprises using "Breeding, reproduction and selling" integration (usually relatively large seed companies) can conduct the VCU testing for varieties they breed via their own trials. These are approved by official authorizations. Smaller seed companies, can form consortiums on their own or with public breeders, using the consortiums' own trials to conduct the VCU testing for varieties they breed. The results can also be officially recognized.

This seed regulation reform has greatly reduced the administrative intervention on the variety entering the market and can have profound impacts on the licensing market of varieties in China. First, this reform would inevitably lead to a significant increase in the number of variety releases in the market in a short period, which might lead to lower licensing fees for varieties. This is because there are still a considerable number of seed companies in China that need new variety licenses from the public or other private sectors. Second, as seed companies' own varieties are officially approved more easily now, they may have less demand for obtaining new variety licenses from public breeders or other private sectors. This also has important implications for licensing fees of new varieties. Finally, these policy implications may be particularly pronounced for small and medium-sized seed companies. This is because they rely heavily on other breeders but lack the sufficient capital or resources to attain the desired licenses of varieties. Studying these issues can help us understand the effects of seed regulation reform on the demand for variety licenses in China. In this way we explore the implications for China's seed breeding system and industry development. Although the literature contains much discussion on the seed regulation reform in China and other countries, no study empirically links the policy with the new variety licensing of seed companies (Huang and Hu 2023; Lesser 2000; Ma and Zhang 2020; Spielman and Kennedy 2016).

Despite variety licensing being common in the seed industry, empirical research on it is extremely scant, especially for China. The licensing market plays an important role in technology commercialization and the licensing pricing issue has long been the focus of scholars and practitioners (Frattini, Bianchi, and Franzó 2019; Kim, Morley, and Chung 2023; Sakakibara 2010; Shen, Coreynen, and Huang 2023). However, because of the limited availability of technology transaction data, few studies have been able to empirically explore the determinants of licensing fees in technology transfer, and none of these studies involve the seed industry (Frattini, Bianchi, and Franzó 2019; Kim, Morley, and Chung 2023; Sakakibara 2010; Shen, Coreynen, and Huang 2023). Rickard, Richards and Yan (2016), Akhundjanov et al. (2020) and Alston and Plakias (2014) studied licensing arrangements for university-bred fruit varieties in the USA. They used licensing data collected from auction experiments or simulations rather than real-world licensing data; however, they did not delve further into licensing fees. Hitherto, there has been no empirical study on the seed licensing market in China.

This study aimed to analyze the impacts of seed regulation reform on the licensing fees of varieties in China, based on a unique actual transaction data of variety licensing. This study is, to the best of our knowledge, the first study to examine the licensing fees in agriculture in the real world. We endeavor to examine whether the release of a large number of varieties in the short term due to the reform necessarily caused a decrease in the licensing fees of varieties, and how this effect differed among different types of breeders and seed companies. These can help us to understand the impacts of market access policy changes in the seed industry and clarify the division of roles between the public and private sectors in crop breeding. We aimed to provide empirical evidence for further deepening the structural reform of the seed industry in the future. The remainder of this article is organized as follows. Section 2 introduces the seed regulation reforms in China. Section 3

introduces the data used in this study. Section 4 documents the licensing market of varieties in China, especially the trend of licensing fees. Section 5 presents the multivariate approach and the econometric model. Section 6 presents the estimation results and the discussion of the impacts of seed regulation reform on the licensing fees of varieties. Section 7 concludes this study with several policy implications.

2 | Reforms in China: Seed Regulation and the Seed Industry

Commercial breeding in China is undergoing a transition from being led by the public sector to being led by the private sector. The seed industry has followed a similar path in both developing and industrialized countries. Pray and Ramaswami (1991) describe a four-stage evolution of national seed systems: farmer seed supply, public breeder and extension departments supplying seeds, commercial seed enterprises marketing public varieties, and private firms marketing their own varieties. According to the above classification, the current commercial breeding in China is in the process of transition from the third stage to the fourth stage. The first seed law in 2000 opened the way for seed commercialization in China, ending monopoly protections for county, prefectural, and provincial seed companies (Hu et al. 2011). At present, "Bred by public research institutions and universities + Produced and distributed by private seed companies + Sold by individual dealers" is a common industry chain model in China's seed industry (Li and Li 2011). The public sector has cost advantages in breeding resources. Their engagement in commercial breeding distorts the value law of the technology market, which makes seed industry enterprises tend to purchase licenses of new varieties at low prices, rather than invest in independent breeding research and development (R&D) (Huang and Hu 2023). In fact, China's seed companies are large in number but generally small in scale (Ministry of Agriculture and rural affairs of the People's Republic of China MARA 2022).

China's seed regulation system, established before seed commercialization, failed to encourage the innovation of seed companies. The system focused too much attention to market access management in the early stage and not enough on the supervision of the seed market in the later stage. The VCU system for varieties is the most important part of seed regulation policies in China, which was established in the 1980s when crop breeding was undertaken exclusively by the government. Under this system, varieties must pass the VCU test and be approved by official authorizations to be eligible for sale. For a long time in the past, the testing rules and release decisions of varieties were mainly based on agronomic performances (yield, adaptability, and disease and insect resistance) with a particular attention to the yield. Before the seed regulation reform at the end of 2015, the system had covered 28 crops (almost all major crops in China), and the testing channels were quite limited (only unified national and provincial VCU testing) (Huang and Hu 2023). Even if the variety had passed the national or province VCU testing, it had a designated sales area and could not be sold outside that area—that means, if a variety had passed the VCU test only in Province A, it could only be sold in Province A, and if companies wanted to sell the variety in Province B, the VCU testing had to be redone in Province B, even if the two provinces were in the same ecological zone. With the increase in varieties bred by seed companies owing to increased private investment in the seed industry, the limited VCU testing channels originally designed for the public breeding system could then no longer meet the needs of enterprises to participate in the test. This resulted in power rent-seeking behaviors, which reduced the incentives for private investment in plant breeding. On top of that, although the VCU system seemed to work as a form of quality certification, a considerable part of the released varieties were not used in practice, meaning the certification might not work well.

The Chinese government being aware of these problems, began to reform the seed regulation system. At the end of 2015, the government revised the Seed Law, and introduced significant reforms to the original seed regulation system, especially the VCU system. The new system covers only main crops, but others can be released or sold as long as they are registered without the VCU testing. Measures were put into place in mid-2016 to clarify that the main crops are rice, maize, wheat, soybean, and cotton[1]. Even for these five main crops, three additional testing channels were added, not limited to the original unified national and provincial VCU testing. First, companies of "Breeding, reproduction, and selling" integration (usually relatively large seed companies) can conduct the VCU testing for varieties they breed via their own trials that are approved by official authorizations. Second, smaller seed companies, can form consortiums on their own or with public breeders, using the consortiums' own trials to conduct the VCU testing for varieties they breed. Those results will also be officially recognized. Third is the mutual recognition of inter-provincial VCU testing data—that is, if a company wants to sell a variety that has been approved for sale in Province A in Province B within the same ecological zone, it only needs to register the variety in Province B, rather than having to redo the VCU testing in Province B as before. The added three testing channels significantly solved the problem of limited opportunities for seed enterprises to participate in the VCU test. Moreover, the new testing rules no longer focused on yield traits solely, and for the special types of varieties (e.g., glutinous rice, silage corn, burst corn), there were few requirements for yield.

This seed regulation reform has significantly reduced the administrative intervention on the variety entering the market, resulting in a marked increase in the number of released varieties in China (Ma and Zhang 2020). For example, in 2000, the number of released varieties for maize and rice was 150 and 279 respectively, and since 2005 the annual number remained at around 500 for over 10 years; from 2017, this number began to rise sharply, increasing to 3779 (maize) and 2287 (rice), respectively, by 2021 (Figure 1). The number of released hybrid crops varieties has grown far more than conventional crop varieties. To some extent, the released varieties reflect the technology supply market for new varieties (Evenson and Gollin 2002). Considering the market risk, Chinese seed companies generally attempt to obtain licenses for varieties that have passed the VCU test and have been approved by official authorizations. Thus, the seed regulation reform has resulted in a significant increase in the supply of new variety licenses

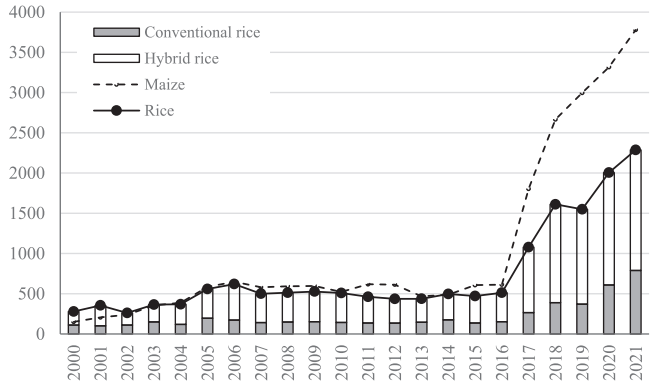

FIGURE 1 | Number of maize and rice varieties released during 2000–2021 period, China. Source: Authors' own calculation based on data from Chinese seed authorities.

rapidly. This will certainly have profound impacts on the licensing market of new varieties in China and is worth intensive exploration.

3 | Data and Samples

This study is predominantly based on a unique dataset from a nationwide in-person survey of seed companies in China. The survey was conducted in 2019 and employed the following multistage sampling. First, to ensure a representative sample, among the 5200 seed companies in the country, enterprises with registered capital of less than 10 million RMB were excluded. This left approximately 2000 companies, which accounted for 84% of the total seed sales in 2017 in China. Second, of the remaining seed companies, the companies whose seed sales of maize, rice, cotton, and soybean accounted for less than 50% of the total sales of the enterprises were excluded, leaving 1038 companies. Third, a stratified random sampling procedure was employed based on the seed sales of each company. The 1038 enterprises from step 2 were sorted by 2017 seed sales and divided into 10 groups, and 10 enterprises were randomly selected in each group. Finally, 115 seed companies from 19 provinces were selected, of which 81 sold maize, 54 rice, 10 cotton, and 11 soybean seeds (Table 1). For each seed company, we collected its basic characteristics and information on the varieties it sold, and especially the license details of varieties licensed from other breeding institutions.

There was an inability to obtain the license details for all the varieties that seed companies had attained licenses from others over the years. For each company we then attempted to collect the license details of only eight license-in varieties, four of these were licensed during the 2017–2019 period, and the other four were among the company's top-selling varieties in 2019. The varieties licensed during the 2017–2019 period could sometimes be among the company's top-selling varieties in 2019, or the company had obtained licenses for fewer than four varieties during the 2017–2019 period. Thus, we could not always obtain license details of the eight license-in varieties for each company in the survey. Ultimately, we obtained license details for 205 varieties licensed during 2004–2019, although 15 were freely licensed from parent companies or public institutions, and 23 were missing licensing fee data (Table 1). We thus obtained 167 license samples with specific licensing fees (Table 1).

TABLE 1 | Number of seed companies samples and their license-in varieties with licensing details.

	Number of companies	Number of license-in varieties with licensing details	
		Total	With licensing fees data
Total	115	205	167
Maize	81	98	71
Rice	54	70	64
Cotton	10	23	19
Soybean	11	14	13

Source: Authors' own survey.

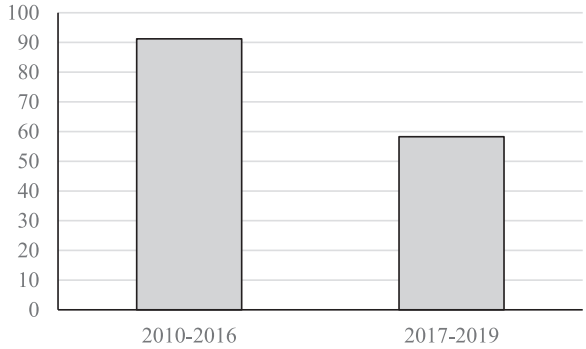

FIGURE 2 | Proportions of Chinese seed companies that have obtained variety licenses from other breeders (%). Source: Authors' own survey.

4 | Licensing Market of Varieties in China

4.1 | Demands and Strategies for Variety Licensing

Most seed companies were obliged to buy licenses of varieties bred by others. As presented in Figure 2, 91% of the seed companies obtained licenses for varieties developed by other breeders before 2017. With the increased private investment in the Chinese seed industry, the R&D capacity of seed enterprises has enhanced significantly, with 42% of companies only selling varieties bred by themselves in 2017–2019, however, 58% of companies still had to rely on other breeding institutions (Figure 2).

Similar to the licensing market in other industries, the contracts for new variety licenses in the Chinese seed industry mainly have three forms of licensing fees—upfront lump-sum fixed-fee, output-based royalty, and a combination of the two (Table 2). Among them, an upfront lump-sum fixed-fee payment has been the most used strategy for variety licensing, although the

TABLE 2 | Strategy for licensing new variety in China.

	Fixed-fee	Royalty	Both
Total	117	39	11
Maize	51	15	5
Rice	40	18	6
Cotton	14	5	0
Soybean	12	1	0

Source: Authors' own survey.

proportion of fixed-fee contracts varies slightly from crop to crop. As presented in Table 2, among the 167 variety licensing contracts with licensing fee data, 117 took a fixed-fee only, 39 used the royalty only, and 11 used a combination of fixed-fee and royalty. Owing to the relatively small number of samples adopting the royalty strategy, and the difficulty in estimating the total licensing fees under this strategy, the empirical analysis of the licensing fees focused on the contracts with fixed-fee payment only. Owing to small samples of contracts for cotton and soybean, the following analysis mainly focused on the 86 (51 + 35) contracts for maize and rice varieties[2]. These 86 licensing contracts involved a sample of 43 seed companies, nearly half of which had only one observation. Moreover, the licensed varieties were all different.

The specific licensing fees were provided for nearly half of the contracts in the survey, and for the remaining contracts for which companies were unwilling to provide explicit licensing fees, we collected data on the nine levels of the licensing fees. They are, "less than 0.1 million RMB" (Level 1), "0.1–0.3 million RMB" (Level 2), "0.3–0.5 million RMB" (Level 3), "0.5–1 million RMB" (Level 4), "1–2 million RMB" (Level 5), "2–3 million RMB" (Level 6), "3–4 million RMB" (Level 7), "4–5 million RMB" (Level 8) and "more than 5 million RMB" (Level 9). The data on the levels showed that, the licensing fees for maize and rice varieties were mainly concentrated in the range from Level 2 to Level 8. Owing to the long license-in period of the contract samples, taking into account inflation, we converted the licensing fees from Level 2 to Level 8 into explicit prices as follows: 1) "0.1–0.3 million RMB" converted into 0.2 million RMB; 2) "0.3–0.5 million RMB" converted into 0.4 million RMB; 3) "0.5–1 million RMB" converted into 0.75 million RMB; 4) "1–2 million RMB" converted into 1.5 million RMB; 5) "2–3 million RMB" converted into 2.5 million RMB; 6) "3–4 million RMB" converted into 3.5 million RMB; 7) "4–5 million RMB" converted into 4.5 million RMB. The deflated licensing fees generally exhibited a downward trend in the past two decades in China (Figure 3).

4.2 | Licensing Fees and the Seed Regulation Reform

To identify the effect of seed regulation reform on the licensing fee of a variety, we categorize the licensing contracts of varieties into two groups according to the year in which the seed companies attained the variety license. Specific reform measures were put into place in mid-2016 and the number of released

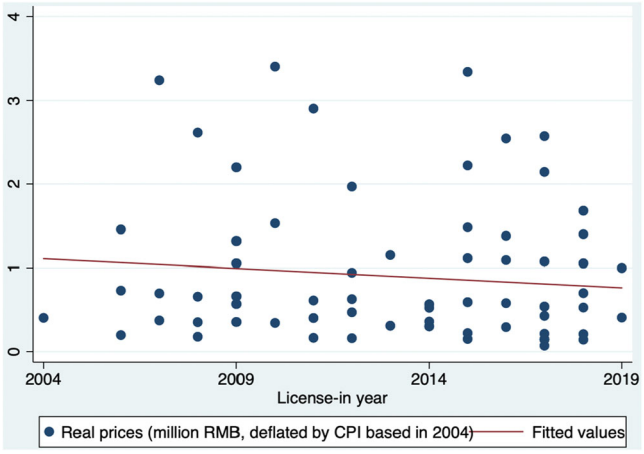

FIGURE 3 | Real licensing fee of a variety in China during the 2004–2019 period. Source: Authors' own survey.

varieties began to increase significantly from 2017. The 86 licensing contracts were accordingly divided into two groups: 57 licensed before 2017 and 29 licensed in 2017 and after (Table 3).

In general, the licensing fee of a variety after the reform is lower than that before the reform. As shown in Table 3 (row 2), the average licensing fee was 0.94 million RMB in 2004–2016, while this number decreased to 0.76 million RMB after the reform.

The decrease in licensing fees was quite different among crops, and the decrease was much higher for conventional crop varieties than that for hybrid crop varieties. Before the reform, the average licensing fee for a maize and a hybrid rice variety were both around at 0.95 million RMB, while the average licensing fee for a conventional rice variety was a little higher at 1.24 million RMB (Table 3). Post the reform, the fees for maize, hybrid rice, and conventional rice all fell, with hybrid crops falling by about 6% ((0.91–0.86)/0.91, ((0.98–0.92)/0.98)) and conventional rice falling by 73% ((1.24–0.33)/1.24).

Most licensed varieties were from public institutions, and post-reform the decrease in licensing fee for a variety from public licensors was more pronounced than that for varieties from private licensors. The licensors in the sample were almost breeders of the licensed varieties, and approximately 70% (26/86) of the licensing contracts were licensed by public licensors (Table 3). The average licensing fee licensed from the public and the private were both around at 0.95 million RMB in 2004–2016, and post-reform the fee licensed from the public dropped to 0.7 million RMB, while the fee licensed by the private decreased only slightly to 0.89 million RMB (Table 3).

Smaller seed companies spent less on obtaining a single variety license, and post the reform, their spending on a variety license dropped more than that of larger seed companies. As shown in Table 3, 87% (75/86) of the variety licenses were purchased by seed companies with registered capital of less than 50 million RMB. Before the reform, seed companies with registered capital of less than 50 million RMB paid an average of 0.94 million RMB for a single variety license, while the companies with registered capital of more than 50 million RMB paid an average of 1.24 million RMB for a variety license (Table 3). Post the

TABLE 3 | Real licensing fees of a variety before and after the seed regulation reform (million RMB, deflated by CPI based in 2004).

	Samples of contracts	2004–2016	2017–2019
Samples of contracts	86	57	29
Total		0.94	0.76
(i) By crop:			
Maize	51	0.91	0.86
Hybrid rice	27	0.98	0.92
Conventional rice	8	1.24	0.33
(ii) By type of licensor:			
Public	60	0.97	0.70
Private	26	0.92	0.89
(iii) By registered capital (million RMB, deflated by CPI based in 2004):			
< 50	75	0.94	0.68
≥ 50	11	1.24	0.98
(iv) By shareholding:			
SOE	13	0.89	0.96
Other	73	0.96	0.71

Source: Authors' own survey.

reform, the former's spending on obtaining a variety license decreased by 28% ((0.94–0.68)/0.94), while the latter's spending on a variety license decreased by only 21% ((1.24–0.98)/1.24).

Unlike the most ordinary seed companies, SOE seed companies have spent slightly more on obtaining a variety license after the reform. Shown in Table 3, 15% (13/86) of the variety licenses were purchased by SOEs. The average licensing fee paid by SOEs for a single variety license has increased from 0.89 million RMB before the reform to 0.96 million RMB after the reform, while the average licensing fee paid by other companies for a single variety license decreased from 0.96 million RMB before the reform to 0.71 million RMB after the reform (Table 3).

5 | Multivariate Approach

Despite the general decline trend in the real licensing fee for a single variety after the reform compared with that before the reform, it is unclear whether this can be attributed to an impact of Chinese seed regulation reform and if so, how significant was the impact. In addition to the policy environment, licensing fees might also have been affected by other factors, so multiple regression analysis is needed. Due to the pooled cross-sectional data structure, the specific model is as follows:

$$\ln(\text{Price}_i) = \beta_0 + \beta_1 \text{Policy}_i + \beta_2 \text{Control}_i + \varepsilon_i,$$

where Price_i is the real licensing fee for the contract i. Policy_i is an indicator of the impacts of seed regulation reform; Specifically, we created a dummy variable that takes the value 1 when the seed company attained the variety license in 2017 and after. Control_i denotes the set of control variables (the specific way each variable is defined is elaborated later); ε_i is the error term.

The literature on the licensing market indicates that in addition to the policy environment, licensing fees are mainly affected by the following five factors. The first and most influential factor is the technology itself, that is, the intrinsic characteristics of the technology (Kim, Morley, and Chung 2023; Sakakibara 2010). The second important factor is the licensor and its characteristics, such as its institutional nature and size (Kim, Morley, and Chung 2023; Sakakibara 2010; Shen, Coreynen, and Huang 2023). Correspondingly, the third factor is the licensee and its characteristics. The fourth is the features of the contract, with exclusivity being the most influential contractual factor in determining the value of the technology (Kim, Morley, and Chung 2023; Somaya, Kim, and Vonortas 2011). Finally, the specific features of the dyad licensor-licensee, such as prior business relationships, can also affect the price of the technology (Frattini, Bianchi, and Franzó 2019).

Specifically, the following control variables are included in the multiple regression analysis.

Type of crop. The first characteristic of licensed varieties to be considered is the type of crop. Hybrid varieties dominate the corn seed market in China, while both hybrid and conventional varieties fill in the rice seed market. Considering some monopoly of hybrid seeds, the licensed varieties were divided into maize, hybrid rice, and conventional rice. In the multiple regression analysis, two dummy variables were then created to indicate hybrid rice varieties and conventional rice varieties, and maize varieties as the base.

Yield of variety. Experimental yield of varieties is used to reflect the quality characteristics of licensed technologies. This is because, for a long time, the VCU testing rules and release decisions of varieties in China focused specifically on yield performance. The experimental yield here is based on VCU testing which usually occurs before a variety license contract is finalized.

Age of variety. Another characteristic of licensed varieties to be considered is the age of variety. This is because variety changes are important means of combating crop losses from pests and diseases in modern intensified farming systems and newer varieties generally have better agronomic performances. In practice, the official decisions for varieties being approved, are often made in the same year or the year after the VCU testing results. The seed companies often enter into a transfer agreement with the breeders of varieties as soon as the VCU testing results are released. Therefore, in calculating the age of a variety, we use the year in which the seed companies obtained the variety license, minus the year in which the variety was first officially approved, plus two.

Type of licensor. The type of licensor is an important factor reflecting the attributes of the licensor. The licensed varieties in our sample originate from two types of licensors: public organization and corporations. We created a dummy variable for these two categories in the multiple regression analysis.

Licensee scale. A larger licensee often means richer financial resources or greater bargaining power in the process of determining the price (Frattini, Bianchi, and Franzó 2019; Sakakibara 2010). For each seed company, indicators of size such as sales and the number of employees were not available for each year, therefore we used the registered capital of seed enterprises to reflect licensee scale. However, most seed companies had changed their registered capital during the sample period. This is because the government greatly raised the minimum capital amount requirement and facilities for companies to sell seed in 2011. To reduce the impact of the above policy on the estimated results, we use a dummy variable to indicate big companies rather than the specific value of registered capital in the multiple regression analysis[3].

Shareholding of licensee. Shareholding is another attribute of a licensee to be considered. Some SOEs are derivatives of public breeding institutions, having advantages in variety resources, which may distort the value law of the technology market. We created a dummy variable to indicate SOEs in the multiple regression analysis.

Exclusivity. Exclusivity is the most influential contractual clause in the process of determining the licensing prices (Kim, Morley, and Chung 2023; Somaya, Kim, and Vonortas 2011). Our sample includes both exclusive and nonexclusive contracts. The former indicates that the variety is given to only one licensee for sale, and the latter means that the variety can be licensed to multiple licensees for sale. A dummy variable was created to indicate the presence of exclusive rights in the multiple regression analysis.

Prior cooperation. The feature of the dyad licensor-licensee to be considered is prior business cooperation. The prior business relationships between licensor and licensee were categorized into two types: prior cooperation and no prior cooperation. We created a dummy variable to indicate the presence of this relationship.

Time trend. To control for any underlying counterfactual trend in licensing fees of new varieties over time, the model includes the time trend variable to indicate the year of licensing.

Summary statistics of all the above variables are presented in Table 4. It shows the average experimental yield of licensed varieties is 9275 kg/ha and the average age is 4 years, 91% of licensing contracts include exclusive clauses and 52% of licensing occurred based on prior business cooperation. Variables of *Price* and *Yield of variety*, employ logarithmic properties in the regression.

Finally, to estimate the equation, an Ordinary Least Squares estimator (OLS) was employed. We also used the propensity score matching (PSM) approach to alleviate the possible sample selection problems between pre- and post-reform licensing contracts varieties and to see whether the results are robust. Considering that there are seed companies with several licenses of varieties in our sample, we ran the regression after clustering

TABLE 4 | Summary statistics of variables used in the regression.

Variable	Mean	Standard deviation	Min	Max
Price (million RMB)	0.89	0.81	0.07	3.40
Policy (Yes = 1; No = 0)	0.34	0.48	0	1
Conventional rice (Yes = 1; No = 0)	0.09	0.29	0	1
Hybrid rice (Yes = 1; No = 0)	0.31	0.47	0	1
Yield (kg/ha)	9275	1646	6139	14567
Age of variety (years)	4.33	3.23	1	18
Private licensor (Yes = 1; No = 0)	0.30	0.46	0	1
Large-scale[a] (Yes = 1; No = 0)	0.13	0.34	0	1
SOE (Yes = 1; No = 0)	0.15	0.36	0	1
Exclusive (Yes = 1; No = 0)	0.91	0.29	0	1
Prior cooperation (Yes = 1; No = 0)	0.52	0.50	0	1
T	10.64	3.86	1	16

Note: Total samples used in regressions are 86.
[a]Large-scale means seed companies with registered capital of more than 50 million.

on firms to consider any unobserved correlation among the errors of the licenses belonging to the same company.

6 | Empirical Results

6.1 | Basic Regression Results

Table 5 reports the estimation results. It presents the general impacts of the seed regulation reform in China on licensing fees of varieties, and the heterogeneous results among different types of breeders and seed companies. In general, the models perform well and are robust.

Of enormous interest are the estimated parameters for the policy variables. Before controlling for the time trend, the estimated parameters of Policy were negative and statistically significant. After controlling for time trends, the coefficient is −0.46 with statistical significance at the 15% level[4] (row 1, Table 5). This implies that ceteris paribus, the reform had brought about a decline of nearly half of the licensing fee of a variety.

Regression results also reveal that the yield and age of a variety, licensee scale, and exclusivity of contract had significant effects on the licensing fee of a variety. As shown in Table 5 (row 9), the coefficient for the log(*yield*) is around 1.4 with statistical significance at the 5% level, implying a 1% increase in yield would result in a 1.4% increase in licensing fee when holding all else constant. The coefficient for *age of variety* is around −0.07 with statistical significance at the 5% or 10% level, implying 1 year increase in age of a variety would result in a 7% decrease in licensing fee when holding all else constant (row 10, Table 5). The coefficient for *large-scale* is around 0.8 with statistical significance at the 5% level, implying ceteris paribus large seed companies pay up to 80% more for a variety license than small ones (row 12, Table 5). The coefficient for the dummy of exclusivity is around 0.5 with statistical significance at the 5% level, implying that ceteris paribus the licensing fee for varieties with exclusive contracts is higher by half than that of varieties without exclusive contracts (row 14, Table 5). These results are consistent with the study on the licensing market in other industry (Fischer and Leidinger 2014; Frattini, Bianchi, and Franzó 2019; Kim, Morley, and Chung 2023).

6.2 | Heterogeneity Analysis

Notwithstanding that the seed regulation reform led to lower licensing fees for a variety in general, this policy's effect varied for different crops. The estimation results indicate that after the reform, the licensing fees of conventional rice varieties decreased the most, followed by maize varieties. By contrast, the reform did not significantly affect the licensing fees of hybrid rice varieties. As presented in Table 5 (column 3), the coefficient for the Policyis −0.44 with statistical significance at the 20% level, implying ceteris paribus a 44% drop in the licensing fee of a maize variety due to the reform. The coefficient for Policy * Conventional rice is—0.56, and the result of the *F* test for sum of Policy and Policy * *Conventional rice* is statistically significant at the 5% level, implying ceteris paribus that the licensing fee of a conventional rice variety had fallen nearly 100% after the reform. However, the result of the *F* test for sum of Policy and Policy * Hybrid rice is not statistically significant, indicating that the licensing fee of a hybrid rice variety was not significantly affected by the reform. These results imply that, the increased competition in the variety licensing market due to the reform, had significantly compressed the market space of conventional varieties which require a higher level of protection considering their reproductive characteristics. With the sowing area remaining stable, the decreased market space of conventional rice varieties means the increased market space of hybrid rice varieties, so their licensing fees were not significantly affected by the reform. The effect of the reform on the fee reduction of maize varieties may be attributed to more intense competition in their licensing market than for other crops, as the number of released maize varieties has increased to a greater extent than that of rice varieties.

We also find that the reform had a great impact on the licensing fees of public-bred varieties, while having no significant impact on that of private-bred varieties. As presented in Table 5 (column 4), the coefficient of Policy are −0.63 with statistical significance at the 10% level, implying ceteris paribus a 63% drop in the licensing fee of a variety licensed by the public licensor post-reform; while the result of the F-test for sum of Policy and Policy * Private licensor is not statistically significant, which means that the licensing fee of a variety licensed by corporations did not decrease significantly post-reform. There are two possible reasons for this. First, public breeding sectors whose main objective is not profit maximization were more vulnerable to the reform and had significantly weaker bargaining power in the variety licensing market, given the surge in the number of released varieties brought about by the reform. Second, varieties bred by the private sector may be more in line with the actual needs of the farming community and may have stronger prices in the variety licensing market.

Interestingly, we find that the reform had a great impact on the licensing fees paid by smaller seed companies while having no significant impact on that paid by bigger seed companies. As shown in Table 5 (column 5), the coefficient of Policy are −0.62 with statistical significance at the 10% level, implying ceteris paribus a 62% drop in the licensing fee of a variety paid by the seed companies with registered capital of less than 50 million RMB after the reform. The result of *F* test for sum of Policy and Policy * Large-scale is not statistically significant. This means that the licensing fee of a variety paid by the companies with registered capital of more than 50 million RMB did not decrease significantly post reform. Larger seed companies always have the financial resources to obtain licenses for the best varieties while smaller companies usually only obtain licenses for the next best varieties due to their financial constraints. The reform may have led to more intense competition in the licensing market for the next best varieties, given that the best varieties were always scarce.

Similarly, we find that the licensing fees paid by SOEs were not affected by the seed regulation reform. As shown in Table 5 (column 6), the coefficient of Policy are −0.65 with statistical significance at the 5% level, implying ceteris paribus a 65% drop in the licensing fee of a variety paid by non-SOEs post reform.

TABLE 5 | Estimation results of licensing fees for varieties.

	log(price)					
	(1)	(2)	(3)	(4)	(5)	(6)
Policy (Yes = 1; No = 0)	−0.58** (0.032)	−0.46^{+} (0.119)	−0.44^{+} (0.164)	−0.63* (0.080)	−0.62* (0.063)	−0.65** (0.030)
Policy * Conventional rice			−0.56 (0.281)			
Policy * Hybrid rice			0.13 (0.868)			
Policy * Private licensor				0.16 (0.781)		
Policy * Large-scale					0.20 (0.694)	
Policy * SOE						0.40 (0.494)
Conventional rice (Yes = 1; No = 0)	−0.05 (0.878)	−0.02 (0.945)	0.36 (0.124)	−0.02 (0.952)	−0.03 (0.926)	−0.07 (0.836)
Hybrid rice (Yes = 1; No = 0)	0.18 (0.568)	0.20 (0.537)	0.16 (0.627)	0.17 (0.608)	0.18 (0.567)	0.18 (0.575)
log(yield)	1.36** (0.017)	1.46** (0.016)	1.39** (0.045)	1.33** (0.027)	1.42** (0.021)	1.40** (0.018)
Age of variety	−0.08** (0.034)	−0.07* (0.053)	−0.07* (0.072)	−0.08** (0.040)	−0.08** (0.040)	−0.07* (0.053)
Private licensor (Yes = 1; No = 0)	0.14 (0.502)	0.15 (0.491)	0.11 (0.622)	0.09 (0.670)	0.14 (0.539)	0.08 (0.719)
Large-scale (Yes = 1; No = 0)	0.81** (0.018)	0.87** (0.019)	0.82** (0.031)	0.82** (0.021)	0.68** (0.034)	0.79** (0.022)
SOE (Yes = 1; Other = 0)	−0.31 (0.392)	−0.36 (0.337)	−0.33 (0.404)	−0.35 (0.366)	−0.30 (0.411)	−0.46 (0.242)
Exclusive (Yes = 1; No = 0)	0.53** (0.031)	0.50** (0.049)	0.49* (0.059)	0.52** (0.030)	0.53** (0.039)	0.53** (0.036)
Prior cooperation (Yes = 1; No = 0)	0.30 (0.225)	0.32 (0.191)	0.31 (0.205)	0.32 (0.234)	0.30 (0.225)	0.30 (0.213)
T		−0.02 (0.481)	−0.02 (0.570)			
Intercept	−13.21** (0.011)	−13.86** (0.010)	−13.26** (0.032)	−12.88** (0.018)	−13.74** (0.014)	−13.50** (0.012)
R^2	0.291	0.295	0.302	0.292	0.292	0.296
p-value of F test for H_0: Sum of the coefficients of "Policy" and "Policy * Conventional rice" is 0			0.022			
p-value of F test for H_0: Sum of the coefficients of "Policy" and "Policy * Hybrid rice" is 0			0.674			
p-value of F test for H_0: Sum of the coefficients of "Policy" and "Policy * Private licensor" is 0				0.264		

(Continues)

TABLE 5 | (Continued)

	log(price)					
	(1)	(2)	(3)	(4)	(5)	(6)
p-value of F test for H_0: Sum of the coefficients of "Policy" and "Policy * Large-scale" is 0					0.241	
p-value of F test for H_0: Sum of the coefficients of "Policy" and "Policy * SOE" is 0						0.632

Note: Total samples used in regressions are 86. The figures in the parentheses are p-values of estimates. **, * and + represent statistical significance at the 5%, 10%, and 20% levels, respectively.

The result of F test for sum of Policy and Policy * SOE is not statistically significant which means that the licensing fee of a variety paid by SOEs did not decrease significantly post reform. There are two possible reasons. First, some SOEs were rich in cash, thus they could obtain licenses for the best varieties, which was always scarce in the licensing market. Second, some SOEs are derivatives of public breeding institutions, having their own variety resources; their spending for a variety license was not affected by the number of released varieties.

6.3 | Robustness Check

6.3.1 | Substitution of The Independent Variable

Since the number of released varieties has surged due to the reform, we also use the number of released varieties to replace the dummy variable that reflects the policy change to see whether the results are robust. Normally, seed companies try to attain the license of varieties which are released in recent years. Therefore, we use the number of varieties released in the year in which the seed company obtained the variety license and its average number in the last 3 years. The number is calculated by crop. Table 6 reports the estimation results after the substitution of the policy variable. It shows that the regression coefficients of the new policy variables are still significant and negative.

6.3.2 | Endogeneity Alleviation With PSM

Although the seed regulation reform is largely an exogenous shock for the licensing market of varieties in China, there may still be some endogenous problems. For example, due to the more diverse selection of varieties after the reform, the licensed varieties could come more from private rather than public breeders. PSM can be used to reduce the correlations between the reform and observable variables of the licensing contracts. It has become a popular technique for estimating average treatment effects (ATE) based on the idea of comparing the outcomes of subjects that are as similar as possible with the sole exception of their treatment status (Abadie and Imbens 2012; Shipman, Swanquist, and Whited 2017). All the control variables mentioned in the previous section are used for matching, and Table 7 reports the estimation results of ATE. It shows that the coefficient for the *Policy* is −0.43 with statistical significance at the 1% level, implying an average decrease of 43% in the licensing fee of a variety due to the reform. This is similar in magnitude to the policy effect of the basic regression results presented in the previous section.

7 | Conclusion

As in other countries, the seed industry in China has faced increasing private investment (Spielman and Kennedy 2016). However, their seed regulation system, established before seed commercialization, could not adapt to such a situation. The system focused extensively on market access management at the early stage and reduced the incentives for private investment in plant breeding. The Chinese government was aware of

TABLE 6 | Robustness checks by using different policy variables.

	log(price)			
	(1)	(2)	(3)	(4)
log(number of maize/rice varieties released in the current year)	−0.41** (0.035)			
log(number of maize/conventional rice/hybrid rice varieties released in the current year)		−0.39* (0.051)		
log(average number of maize/rice varieties released in each of the last three years)			−0.44* (0.090)	
log(average number of maize/conventional rice/hybrid rice varieties released in each of the last three years)				-0.42^{+} (0.114)
Control variables	Yes	Yes	Yes	Yes
Intercept	−10.71** (0.046)	−10.61** (0.048)	−9.32 (0.108)	−9.24 (0.110)
R^2	0.282	0.277	0.261	0.259

Note: Total samples used in regressions are 86. The figures in the parentheses are p values of estimates. **, * and $^{+}$ represent statistical significance at the 5%, 10%, and 20% levels, respectively.

these problems and introduced significant system reforms. These reforms have greatly reduced the administrative intervention on the varieties entering the market and can have profound impacts on the licensing market of new varieties. However, the licensing issue in the seed industry has barely been explored owing to the limited availability of real licensing data (Akhundjanov et al. 2020; Rickard, Richards, and Yan 2016). This study aimed to analyze the impacts of seed regulation reform on the licensing fees of new varieties in China based on unique actual transaction data of new variety licensing.

The results presented herein indicate that variety licensing is very common in China's seed industry, with 91% and 58% of the seed companies obtaining licenses for varieties developed by other breeders before 2017 and after, respectively. An upfront lump-sum fixed-fee payment has been the most used strategy for this licensing. The deflated licensing fees have generally exhibited a downward trend in the past two decades in China.

The multivariate analysis estimation results indicate that the seed regulation reform led to an average decline of nearly half of the licensing fee of a variety. However, this policy effect varied for different crops. The reform resulted in a 44% and nearly 100% decrease in the licensing fee of a maize variety and a conventional rice variety, respectively. However, the fee of a hybrid rice variety was not significantly affected by the reform. Furthermore, the reform resulted in a 63% drop in licensing fee of a public-bred variety, while having no significant impact on that of private-bred varieties. After the reform, the licensing fee of a variety paid by smaller seed companies and non-SOEs decreased by 62% and 65%, respectively, while the fees paid by bigger seed companies and SOEs were not significantly affected by the reform.

The results also indicate that in addition to the seed regulation reform, the yield and age of a variety, licensee scale, and exclusivity of contract had significant effects on the licensing fee of a variety. On average, a 1% increase in yield would result in a 1.4% increase in licensing fee of a variety, a year increase in age would result in a 7% decrease in licensing fee, large seed companies would pay up to 80% more for a variety license than small ones. The licensing fee for varieties with exclusive contracts was higher by half than that of varieties without exclusive contracts.

This study's findings have important implications for China's plant breeders, policy makers, and seed enterprises. First, the reform greatly reduced the cost of obtaining new variety licenses for small and medium-sized seed companies. Second, the licensing market for self-pollinated crop varieties had been hit hard by the reform. This could greatly reduce the income from licensing varieties for such crop breeders. Finally, the reform caused a serious decline in the income of public institutions whose income relied heavily on the licensing fees of new varieties, and it is necessary to reorganize their roles in plant breeding research.

This study adds new insights to the literature on licensing markets. Previous studies has explored factors influencing technology commercialization such as the intrinsic characteristics of the

TABLE 7 | Average treatment effect (ATE) with PSM.

	Coefficient	AI Robust Standard Error	Z-statistic	*p*-value
Policy (Yes = 1; No = 0) (1 vs. 0)	−0.43***	0.137	−3.13	0.002

***represents statistical significance at the 1% level.

technology, the bargaining power of the licensors and licensees, and the features of the contracts (Kim, Morley, and Chung 2023; Sakakibara 2010; Shen, Coreynen, and Huang 2023; Somaya, Kim, and Vonortas 2011). However, limited attention was given to exploring the role of changes in the institutional environment. This study confirms the role of market entry deregulation on licensing markets and contributes to the understanding of factors driving technology commercialization.

Moreover, the results of this study have policy implications beyond the seed industry. The study provides additional evidence of the impact of market entry deregulation on reducing external transaction costs for market participants. Similar results are found in the relevant literature in other industries (Liebich 1999; Pan, Huang, and Jin 2023). However, compared to the literature on other industries, this study found that more of the above cost reductions occurred in small and medium-sized enterprises in low-concentration industries. The study also found that the price for technologies with strong externalities and that are not easily protected would be impacted the most by the deregulation reform.

Author Contributions

Cheng Xiang: methodology, data curation, investigation, formal analysis, funding acquisition, project administration, writing–original draft, writing–review and editing, conceptualization, software, validation, supervision. **Rui Yang:** data curation, oftware, formal analysis. **Xia Wang:** data curation, investigation. **Jikun Huang:** conceptualization, funding acquisition, methodology.

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Conflicts of Interest

The authors declare no conflicts of interest.

Ethics Statement

The authors have nothing to report.

Data Availability Statement

Data are available on request due to privacy restrictions. The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions.

Endnotes

[1]Maize, rice, wheat and soybeans are among the largest crops planted in China. Maize and rice are the largest and second largest crop in China, respectively. The annual area for these two crops accounted for approximately 40% of China's total crop area in the past twenty years.

[2]There is a licensed rice variety that had not passed the VCU test and been not approved by official authorizations, a variety whose licensing fees were more than double the maximum license price of other varieties, and three upland rice varieties with agronomic performances and target markets that differ significantly from ordinary rice varieties in China. We excluded them in the empirical analysis.

[3]We also attempted to use the specific registered capital value to replace this dummy variable in the multiple regression analysis, and the estimated results are similar to those shown in the paper.

[4]Because the sample is relatively small, here we include *p*-value in the parentheses, we can increase the significant level to a little more than 10% (Wooldridge 2019).

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