Establishment and Study of an Evaluation Model for the Exploitation Effect of University Scientific and Technological Patents

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Abstract—Due to the lack of sufficient understanding by the public of the process and mechanism of how university patents are exploited, the exploitation effect of university patents is not satisfactory. Therefore, it is necessary to effectively evaluate the exploitation effect of university patents in order to explore a reasonable path for and expand the role of university patent exploitation. Currently, there has been few research on how to evaluate the exploitation effect of university patents. To this end, this paper focuses on university scientific and technological patents and explores the effective evaluation method for the exploitation effect of these patents. First, market share, market benefit, patented technology maturity, enterprise nature and government support were selected as the evaluation indicators for the exploitation effect of the scientific and technological patents in colleges and universities in the study area. It was proposed that the five influencing factors and the exploitation effect of university scientific and technological patents interact with and influence each other. Then a combined model based on grey prediction GM (1,1) model and BP neural network model was constructed for the evaluation of the exploitation effect of scientific and technological patents in colleges and universities, which proved to have better prediction performance. The experimental results proved the effectiveness of the prediction model, and also verified the interactions between the five influencing factors and the exploitation effect of university scientific and technological patents.

Keywords—university patent exploitation, exploitation effect evaluation, evaluation model

1 Introduction

In 2021, patents of colleges and universities were licensed for 27,000 times nationwide, a year-on-year increase of 33%, which was nearly twice the overall growth rate of national patent transfer licenses. This shows that colleges and universities are the "treasure houses" of intellectual properties such as patents, and are holding a large number of unexploited patents [1–7]. The patentees or licensors of patents in the colleges and universities may manufacture, use and sell the patented products or patent use methods for production or business purposes, or have others exploit the patents in legally recognized ways [8–15]. For a long time, in terms of patent exploitation and transformation, there has always been a "dilemma" where colleges and universities find it hard to transform their research results and small and medium-sized enterprises (SMEs) to acquire technologies. The reason is that the public lacks sufficient understanding of the process and mechanism of how university patents are exploited, resulting in unsatisfactory exploitation effect of university patents [16–21]. Therefore, it is necessary to effectively evaluate the exploitation effects of university patents in order to explore a reasonable path for and expand the role of university patent exploitation.

Having an understanding of the characteristics of and influencing factors to a company's patent strategy can help improve innovation capabilities. In order to understand the implementation status of enterprises' patent strategies, Wang et al. [20] conducted a survey among 863 enterprises in China, and found that the R&D ability, awareness of patent application strategy and comprehensive intellectual property management ability of a company are the three important factors affecting the implementation of its patent strategy. In the process where patents are transformed into real productivity, it is crucial to understand the characteristics of and influencing factors to patent exploitation. Wang et al. [21] collected the data of 1,378 patents from 639 SMEs in Zhejiang Province through a survey, and empirically studied the effects of patent promotion policies, R&D investment, R&D cooperation models and strategic management of patents on the exploitation of patents by the SMEs in China. The results show that they all significantly affect patent exploitation. However, universities and private companies often find it difficult to collaborate with each other. Yamaguchi et al. [22] focused on patent creation and patent-based technology transfer, as universities have created many patents, but have not carried out enough patent-based technology transfers related to the created patents. It aimed to reveal the factors that influence patent creation, namely patent filings and patent rights, and patent-based technology transfer, that is, the licensing and licensing income by universities. Dahlborg et al. [23] extended the previous work on commercialization of academic research by longitudinally tracking patent ownership transfers. It developed a conceptual framework for the academic patent transfer modes, distinguished between patents transferred through researchers' own efforts (autonomous mode), university support intermediaries (bridge mode), or companies (corporate mode). The results show that SMEs are the largest absorbers of academic patents. The findings have potential implications for the benchmarking of universities and the development of more targeted internal innovation support. At present, China has become a big producer of patents, where the number of patent filings has been ranking first in the world for many years. With the number of patents increasing, the quality of patents has begun to attract people's attention. Currently, there is no clear evaluation method for patents in China. Liu et al. [24] introduced this model into the Chinese patent quality evaluation model through transfer learning and active learning, thereby reducing the workload of manual labeling. The evaluation results showed that the method used in the experiment achieved a good transfer effect, with Micro-F1 reaching 74%.

Through review of the existing literature, it can be seen that domestic and international research has mostly focused on finding ways to improve the quality of patents so as to increase the enthusiasm of university teachers for patent exploitation, and few has studied the evaluation of the exploitation effect of university patents. In the limited research on this subject, only one or two evaluation indicators were used to evaluate the exploitation effect of university patents, and the researchers did not study from the different dimensions of the influencing factors to the exploitation effect. To this end, this paper takes university scientific and technological patents as the object and explores the effective evaluation method for the exploitation effect of these patents. First, Section 2 selects market share, market benefit, patented technology maturity, enterprise nature and government support as the evaluation indicators for the exploitation effect of the scientific and technological patents in colleges and universities in the study area. It proposes that the five influencing factors and the exploitation effect of university scientific and technological patents interact with and influence each other. Section 3 constructs the grey prediction GM (1,1) model and the BP neural network model for the evaluation of the exploitation effect of scientific and technological patents in colleges and universities. Section 4 constructs a combined model to improve the prediction performance with respect to the exploitation effect of scientific and technological patents in colleges and universities. The experimental results prove the effectiveness of the prediction model, and also verify the interactions between the five influencing factors and the exploitation effect of university scientific and technological patents.

2 Selection of evaluation indicators

In order to investigate the effects of external factors related to the market, enterprises, and government on the exploitation of scientific and technological patents in colleges and universities, market share, market benefit, patented technology maturity, enterprise nature and government support were selected as the evaluation indicators in this paper.

1) The market share of a large or medium-sized enterprise largely determines its innovation effect in production process improvement, product R&D and product upgrading. Therefore, this indicator was selected as a factor that affects the exploitation effect of university scientific and technological patents, denoted as *MS*.
2) The higher the market benefit of an enterprise, the higher its enthusiasm in making innovations in production process improvement, product R&D and product upgrading. For some companies, however, high market benefits may also lead to companies only considering maintaining the status quo and lacking interest in new market and product development. Therefore, the ratio of the total market benefit of the enterprise to the total annual output value was selected as the second factor that affects the exploitation of scientific and technological patents in colleges and universities, denoted as *MB*.
3) A mature patented technology usually needs to be feasible both technologically and economically. The maturity of a patented technology is usually measured by whether it can be applied in batches and whether it can be accepted by the market. Considering that the research object of this paper is the exploitation effect of scientific and technological patents in colleges and universities, the maturity of patented technology was selected as the influencing factor, denoted as *PTM*.

4) The patent exploitation process is relatively complicated, and each link involved may require the engagement of scientific and technological professionals who understand the specifics of the patent. Therefore, it is very important whether the enterprise can effectively encourage the innovative activities of scientific and technological talents. In addition, the enterprise's awareness of patent exploitation and acceptance of patent results also have direct effects on its innovations. Therefore, it is necessary to take into account the nature of the enterprise when considering the factors to the exploitation effect of scientific and technological patents in universities. In this paper, this indicator is denoted as *EN*.
5) Government support mainly includes investment policies, incentive policies and laws and regulations, that is, the provision of financial support for patent exploitation, establishment of public patent information platforms and regulation of the patent exploitation process. The government's financial support and convenient access to patent information have a beneficial effect on enterprises' exploitation efficiency of scientific and technological patents in colleges and universities. The regulation of the patent exploitation process also effectively reduces the risk of patent trading and promotes the completion of patent exploitation as soon as possible. Therefore, government support was selected as a factor that affects the exploitation effect of scientific and technological patents in colleges and universities, denoted as *GS*.

In view of the fact that there is no evaluation indicator for the exploitation effect of university scientific and technological patents in various research literatures, the evaluation of the exploitation effect of university scientific and technological patents in this paper refers to the prediction of the exploitation effect of these patents based on the status quo of the influencing factors. The enterprises that exploit scientific and technological patents of colleges and universities in the study area are mainly high-tech enterprises. Considering the data availability, market share, market benefit, patented technology maturity, enterprise nature and government support were selected as the evaluation indicators for the exploitation effect of the scientific and technological patents of colleges and universities in the study area. Taking into account the attributes and dimensions of the influencing factors, the data collected were divided and normalized.

From the above analysis of the five indicators, namely market share, market benefit, patented technology maturity, enterprise nature and government support, it can be seen that each influencing factor can affect the exploitation effect of university scientific and technological patents. This means that, when a certain factor changes, the exploitation effect of a university scientific and technological patent will change accordingly, and when the latter changes, it will also exert an effect on some factors. Therefore, it can be said that the five influencing factors and the exploitation effect of university scientific and technological patents interact with and influence each other. For this reason, it is necessary to predict the exploitation effect of university scientific and technological patents based on all the independent variables. To sum up, this paper chose to use the combination of qualitative and quantitative methods to construct the evaluation model for the exploitation effect of university scientific and technological patents, and conducted related research.

3 Construction of the evaluation and prediction model

3.1 Dimensionality reduction

The evaluation rules for the five influencing factors require principal component analysis for dimensionality reduction. First of all, the original data of the evaluation rules for the exploitation effect of scientific and technological patents in universities and colleges were processed. In this paper, normalize the data as follows:

$$C_i = \frac{A_i - Mean}{Standard\ deviation} \tag{1}$$

Then, construct the correlation coefficient matrix and calculate the eigenvalues and eigenvectors. After the feature selection is completed, generate the component matrix, and further orthonormalize the data as follows:

$$o_{ij} = \frac{x_{ij}}{\sqrt{\mu_i}} \tag{2}$$

The following formula is the principal component expression:

$$G = CA_1 + CA_2 + CA_3 + \ldots CA_9 \tag{3}$$

3.2 Grey prediction GM (1,1) model

After the principal component analysis, the original data sequence of the influencing factors to the exploitation effect of university scientific and technological patents can be obtained as follows:

$$A^{(0)} = (a^{(0)}(1), a^{(0)}(2), \ldots, a^{(0)}(m)), a^{(0)}(p) \geq 0, p = 1,2,\ldots,m \tag{4}$$

The new sequence can be obtained by weighting the original sequence $A^{(1)}$:

$$A^{(1)} = (a^{(1)}(1), a^{(1)}(2), \ldots, a^{(1)}(m)), p = 1,2,\ldots,p \tag{5}$$

$$C^{(1)}(p) = \varepsilon a^{(1)}(1) + (1-\varepsilon)a^{(1)}(p-1), p = 1,2,\ldots,p \tag{6}$$

Build the grey prediction GM (1,1) model based on the obtained new sequence. Suppose that the undetermined coefficients are represented by ε and α. The following formula shows the constructed grey differential equation:

$$\phi(p) + \varepsilon c(1)(p) = \alpha \tag{7}$$

Let ε* satisfy:

$$\varepsilon^* = \begin{bmatrix} \dfrac{\varepsilon}{\alpha} \end{bmatrix} \tag{8}$$

Estimate ε* based on the least squares method, and then there is:

$$\begin{bmatrix} \varepsilon^* \\ \lambda^* \end{bmatrix} = (Y^{\gamma} Y)^{-1} Y^T B \tag{9}$$

$$Y = \begin{bmatrix} -C^{(1)}(2) & 1 \\ \vdots & \vdots \\ -C^{(1)}(p) & 1 \end{bmatrix}$$
$$B = \begin{bmatrix} a^{(0)}(2) \\ a^{(0)}(3) \\ \vdots \\ a^{(0)}(p) \end{bmatrix} \tag{10}$$

To solve the constructed GM (1,1) model, the following formula gives the expression of the corresponding time response function:

$$\hat{A}(1)(p+1) = \left[A^{(0)}(1) - \frac{\alpha}{\varepsilon} \right] o^{-\varepsilon p} + \frac{\alpha}{\varepsilon}, p = 1, 2, \ldots, m \tag{11}$$

Restore the predicted value of the exploitation effect, and there is:

$$\hat{A}(0)(p+1) = \hat{A}(1)(p+1) - \hat{A}(1)(p) = (1 - o^{\varepsilon}) \left(A(0)(1) - \frac{\alpha}{\varepsilon} \right) o^{-\varepsilon p}) \tag{12}$$

Then, carry out tests on the development grey number and residual of the predicted value of the exploitation effect. The absolute error is calculated as follows:

$$\tilde{O}(0)(i) = a^{(0)}(p) - \tilde{A}(0)(p) \tag{13}$$

The relative residual is calculated as follows:

$$\Phi(p) = \frac{a^{(0)}(p) - \hat{A}(0)(p)}{a^{(0)}(p)}, m = 1, 2, \ldots, m \tag{14}$$

If all $|\Phi(p)|$ are less than 0.2, it means that the predicted value can meet the prediction standard; if all $|\Phi(p)|$ are less than 0.1, it means that the predicted value can meet a higher prediction standard. The following formula shows how to test the grade ratio deviation value:

$$GU(l) = 1 - \frac{1 - 0.5\varepsilon}{1 + 0.5\varepsilon}\mu(p) \tag{15}$$

If all $|GU(l)|$ are less than 0.1, it means that the predicted value can meet the higher prediction requirement.

Further establish correlations between the independent variables – the five influencing factors – and the dependent variable – the exploitation effect of scientific and technological patents in colleges and universities, and complete the regression analysis. Perform multiple linear regression on B before and after normalization, and there is:

$$CB = \beta_1 G_1 + \beta_2 G_2 + \ldots + \beta_0 \tag{16}$$

$$B = \gamma_1 A_1 + \gamma_2 A_2 + \ldots + \gamma_0 \tag{17}$$

Finally, substitute the historical evaluation data of the exploitation effect of university scientific and technological patents into the above formula to obtain the predicted value of the exploitation effect.

3.3 BP neural network model

The *BP* neural network is a hierarchical network system containing input layers, hidden layers and output layers. In this paper, an optimized *BP* neural network was constructed to verify the correctness of the predicted value of the exploitation effect of scientific and technological patents in universities.

First, determine the network structure parameters and the initialized weights and thresholds, and preset the prediction error, prediction precision and maximum number of iterations of the model. Suppose the number of neurons on the output layer is denoted by m, that the expected output result of the neurons on the i-th output layer c_i, that the actual output result of the neurons on the i-th output layer b_i, and that the error O_l, then:

$$O_l = \frac{1}{2}\sum_{i=1}^{m}(c_i - b_i)^2 \tag{18}$$

Determine whether the prediction error of the exploitation effect is less than the preset value. If it is less than the preset value, the model learning is completed, and then perform further sample check. If it is greater than the preset value, a new round of iterative learning needs to be performed.

If the number of iterations reaches the preset maximum value, the model stops learning and the modeling ends. If it is less than the preset value, it needs to perform a new round of iterative learning until the model finishes learning.

4 Construction of the combined prediction model

Different models have different applicable scenarios and require different conditions, and also have different advantages and disadvantages. To predict the exploitation effect of university scientific and technological patents, these models also have different precisions. In order to improve the prediction performance regarding the exploitation effect of scientific and technological patents in universities, a combined model integrating the advantages of different prediction models was constructed in this paper, which improves the overall prediction precision.

The models were combined in a linear way, and weighted based on their prediction errors. The model with a larger prediction error was given a smaller weight.

In this paper, the *Shapley* value method was used to obtain the model weights. Suppose that the marginal contribution of the combined model in predicting the exploitation effect of university scientific and technological patents is denoted by $\theta(|R|)$; that the i-th prediction model for the exploitation effect of university scientific and technological patents by i, that the *Shapley* value of the i-th model by O'_p, i.e. the distributed error, the combination containing all prediction models by r, that the number of prediction models in the combination by $|r|$, the models excluding i in r by $s\backslash i$, and that the number of combined prediction models by m. The following is the error distribution formula of the *Shapley* value:

$$O'_i = \sum\nolimits_{R \subseteq R_i} \theta\left(|R|\right)(O(r) - O(r)\setminus i), i = 1, 2, \ldots, m \tag{19}$$

where,

$$\theta\left(|R|\right) = \frac{\left(m - |r|\right)!\left(|r| - 1\right)}{m!} \tag{20}$$

Assuming that the total distributed error value in the prediction of the exploitation effect by the combination is represented by O, and that the weight of each prediction model by λ_i, then the following is the weight calculation formula:

$$\lambda_i = \frac{1}{m-1} * \frac{O - O_i}{O} \tag{21}$$

Suppose that the predicted value of the exploitation effect of university scientific and technological patents given by the combined model at time j is represented by B^*_j, that the weight of the GM (1,1) model by λ_1, that the weight of the *BP* neural network model by λ_2, that the predicted value given by the GM (1,1) model for the j-th year by B^*_{1j}, and that the predicted value given by the *BP* neural network model for the j-th year by B^*_{2j}. After the weight calculation is completed, the prediction models for the exploitation effect of university scientific and technological patents can be combined, in the following form:

$$B^*_j = \lambda_1 B^*_{1j} + \lambda_2 B^*_{2j} \tag{22}$$

5 Experimental results and analysis

Table 1. Predicted values of the combined model and prediction errors

Year	Actual Value	Predicted Value	Absolute Error
2010	16.27	13.269	0.815
2011	18.42	22.584	1.629
2012	21.68	23.528	1.528
2013	23.52	27.416	0.714
2014	25.14	29.358	0.426
2015	26.35	22.615	0.958
2016	27.41	27.421	0.536
2017	28.62	20.312	0.948
2018	22.38	29.658	0.051
2019	20.69	23.528	1.258
2020	24.15	28.152	2.639
MAE			1.046

Substitute the prediction results of the GM (1,1) model and the *BP* neural network model into the calculation formula, and then the predicted value of the combined prediction model can be obtained. Table 1 shows the predicted values and prediction errors of the combined model, and Figure 1 illustrates the prediction fitting results of the combined model.

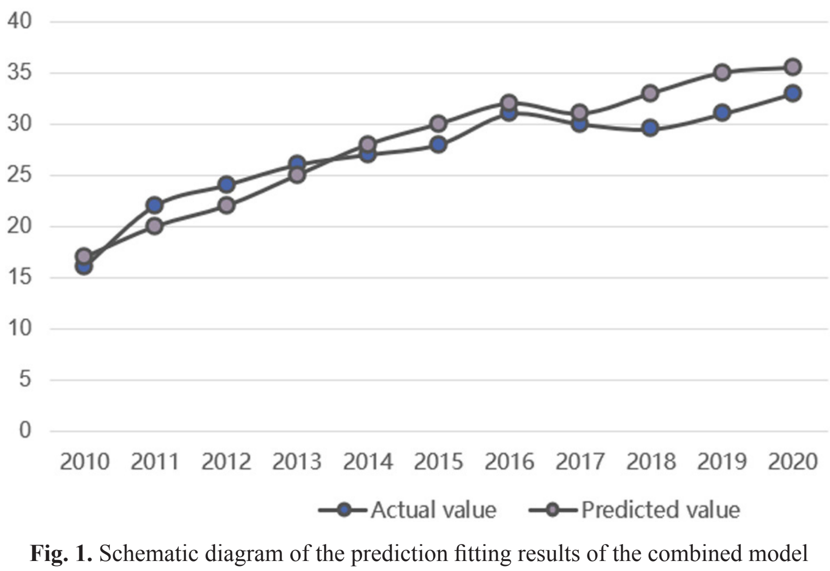

Fig. 1. Schematic diagram of the prediction fitting results of the combined model

As can be seen from the chart, during the study period of 2010–2020, the exploitation effect of university scientific and technological patents showed a steady upward trend year by year under the combined effect of various influencing factors. The average prediction error of the combined prediction model was 1.046, which is satisfactory. Substitute the predicted values of the influencing factors to the exploitation effect of university scientific and technological patents into the GM (1,1) model, the *BP* neural network model and the combined prediction model, respectively. Table 2 shows a comparison of the prediction results, from which, it can be seen that the exploitation effect of scientific and technological patents in colleges and universities is gradually improving, which is basically consistent with the trends of most data during the study period of 2010–2020.

Table 2. Comparison of the prediction results regarding the exploitation effect of scientific and technological patents in colleges and universities

Year	GM (1,1) Model	BP Neural Network Model	Combined Prediction Model
2021	23.15	22.59	27.41
2022	29.41	25.63	21.38
2023	23.62	29.58	20.53
2024	31.48	24.61	25.18
2025	35.65	23.55	22.69

Take the exploitation effect of university scientific and technological patents as the dependent variable, and market share, market benefit, patented technology maturity, enterprise nature and government support as the influencing factor variables, and use the software Frontier4.1 to process the relevant data collected during the study period, and then, the exploitation efficiency values of scientific and technological patents in universities in the study area under the action of the five influencing factors can be obtained. Figure 2 shows the changing trend of the efficiency value of scientific and technological patents in universities in the study area.

Table 3. Statistics of the exploitation efficiency values of scientific and technological patent in universities in the study area

	Max Value	Min Value	Mean	SD	Average Growth
Mechanical	0.7152	0.4629	0.5328	0.1347	2.36%
Material	0.4185	0.0582	0.2691	0.0585	16.29%
Electrical & electronics	0.6582	0.3519	0.4825	0.0263	1.74%
Communication control	1.0251	0.1625	0.6297	0.2659	−1.28%
Chemical	1.0026	0.3524	0.5296	0.2348	−12.58%

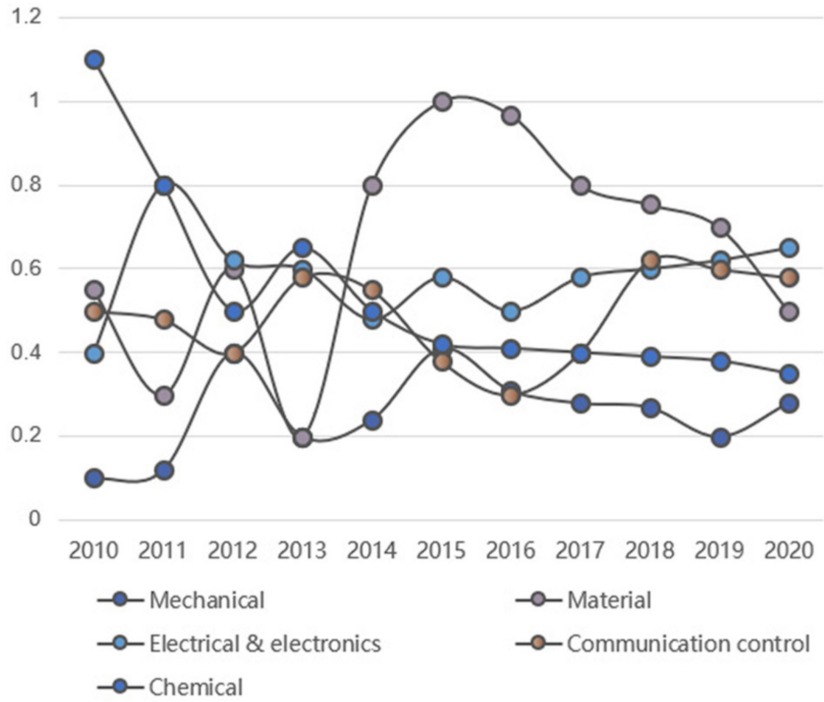

Fig. 2. Changing trends of the exploitation efficiency values of different scientific and technological patents in universities in the study area

It can be seen from the chart that the communication control and chemical patents saw effective exploitation efficiency during the study period, and the corresponding minimum values of the exploitation efficiency were 0.1147 and 0.2074, respectively. Compared with those of other categories, the data of the communication control and chemical patents during different years changed more significantly. On the whole, the exploitation efficiency values of university scientific and technological patents in the mechanical, communication control and chemical categories are in the range of [0.40, 0.8], while those of the material and electrical and electronics categories are lower than 0.5. Regarding the number of patents of the five categories exploited, the mechanical, material electrical and electronics categories saw their average growths greater than 0, of which the material patents had the most obvious increase and the highest average growth; communication control and chemical patents saw their average annual growths less than 0, especially the chemical patents, for which, the average growth was −9.75%, indicating that the exploitation efficiency of this patent category was on a downward trend.

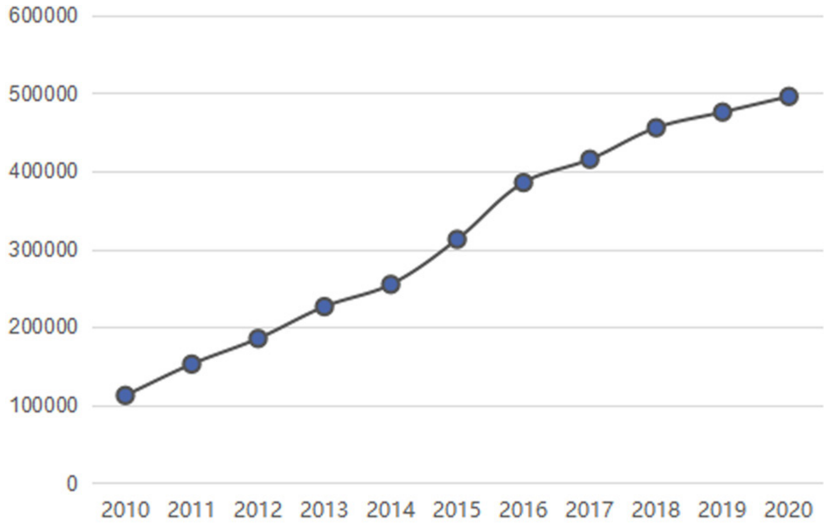

Fig. 3. Changing trend of the number of scientific and technological patents in colleges and universities leading to the increase of the market share of enterprises

In order to verify the interactions and mutual influences between the five influencing factors, namely market share, market benefit, patented technology maturity, enterprise nature and government support, and the exploitation effect of university scientific and technological patents, this paper summarized the number of scientific and technological patents leading to the increase in enterprises' market shares, market benefits, patented technology maturity, improvement in the enterprise nature, and optimization of the government support policies. Figures 3 and 4 show the changing trends of the number of scientific and technological patents that have led to increase in the market shares and market benefits of enterprises. It can be seen that the number of university scientific and technological patents that led to the improvement of enterprises' market shares and market benefits increased by 3 times and 7 times, respectively within the study period. Therefore, promoting the exploitation of patents, which are part of the innovation achievements of colleges and universities, is a necessary measure to drive the social and economic development in this big environment where innovation and entrepreneurship are encouraged.

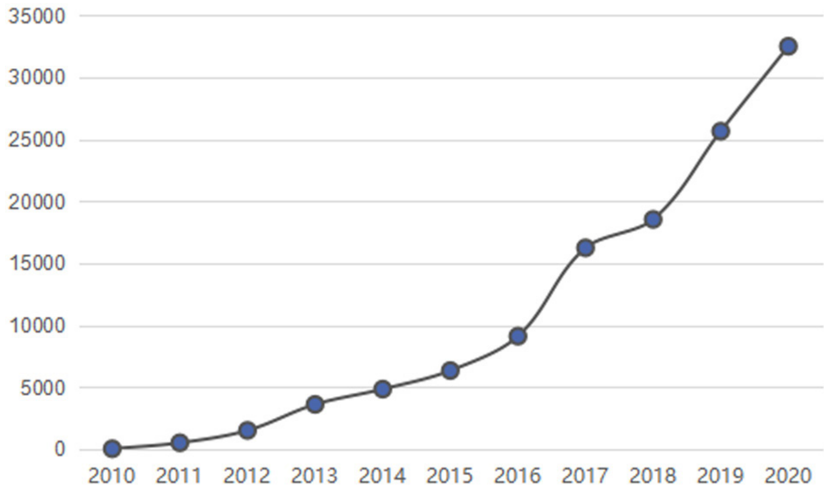

Fig. 4. Changing trend of the number of scientific and technological patents in colleges and universities leading to the improvement of market benefits

Figure 5 shows the changing trend of the number of scientific and technological patents in colleges and universities that lead to the improvement of patented technology maturity. It can be seen that the trend of the number of technological patents leading to the improvement of patented technology maturity increased by nearly 5 times, indicating that the quality of patents in colleges and universities improved year by year. This had something to do with the increase in the number of patents completed by colleges and universities. However, the increase in the number of patents exploited was still lower than that in the number of high-quality patents, indicating that colleges and universities need to further implement incentive measures to promote the exploitation of patents.

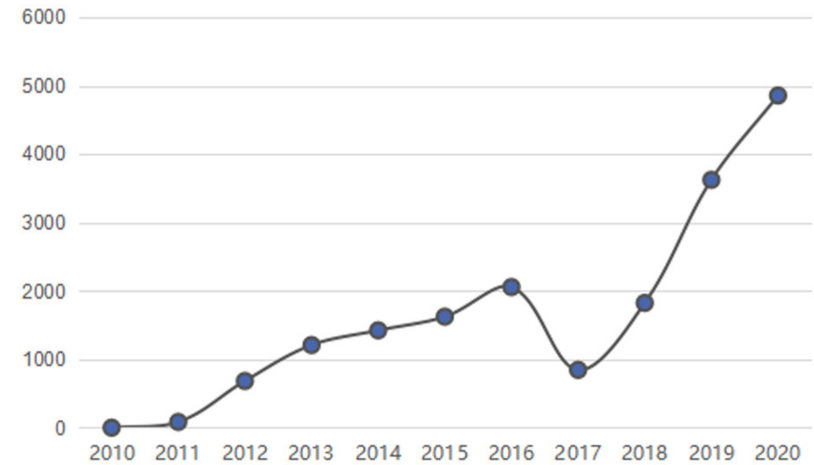

Fig. 5. Changing trend of the number of scientific and technological patents in colleges and universities leading to the improvement of patented technology maturity

Figures 6 and 7 show the distribution of improvements in enterprise nature and the distribution of optimization in government support policies, respectively. As can be seen, with the increase in the number of patents exploited by colleges and universities, enterprises have paid more attention to the innovation activities of scientific and technological talents, and their awareness of patent exploitation and acceptance of patent achievements have also been effectively improved. According to the problems in the patent exploitation process, the government actively facilitated funding for patent exploitation, built public patent information platforms, and restricted and regulated the patent exploitation process through laws and regulations. Different enterprises saw different levels of improvement in their natures, and government support policies were also optimized to varying degrees.

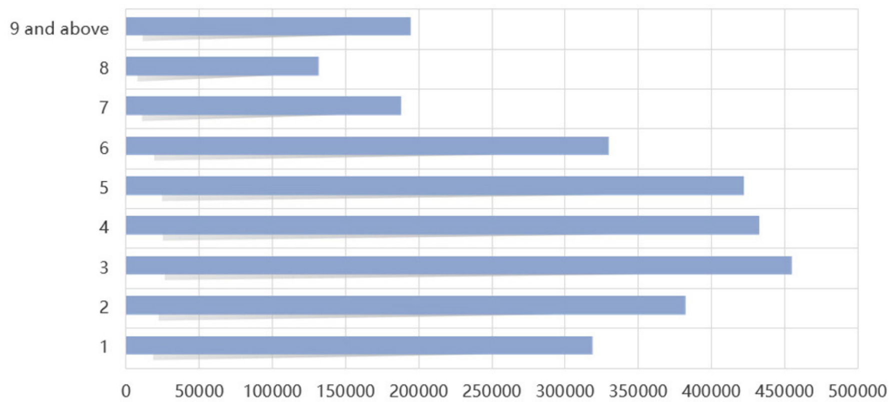

Fig. 6. Distribution of improvements in enterprise nature

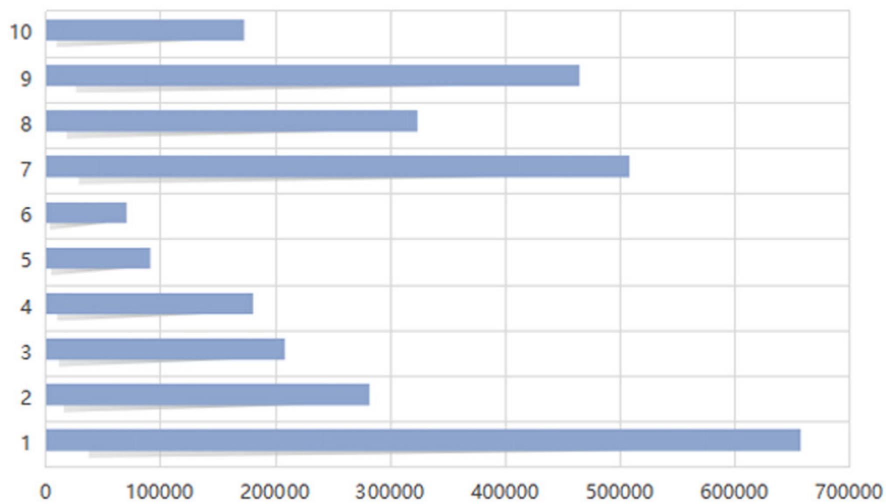

Fig. 7. Distribution of optimization in government support policies

6 Conclusions

This paper focused on university scientific and technological patents and explored the effective evaluation method for the exploitation effect of these patents. First, market share, market benefit, patented technology maturity, enterprise nature and government support were selected as the evaluation indicators for the exploitation effect of the scientific and technological patents in colleges and universities in the study area. It was proposed that the five influencing factors and the exploitation effect of university scientific and technological patents interact with and influence each other. Then a combined model based on grey prediction GM (1,1) model and BP neural network model was constructed for the evaluation of the exploitation effect of scientific and technological patents in colleges and universities, which proved to have better prediction performance. The predicted values and prediction errors of the combined model were given, and the prediction results of the exploitation effect of university scientific and technological patents were compared through an experiment, which verified the effectiveness of the prediction model. Finally, the statistics of the exploitation efficiency of scientific and technological patents in universities in the study area were summarized, and the interactive relationship between the five influencing factors and the exploitation effect was verified.

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