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Research on Correlation Control of Subjective Patent Indicators Based on Progressive Constraint

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Abstract: *Patent indicator evaluation is a relatively objective patent quality evaluation method recognized by academia. Some subjective patent indicators are often related, which to some extent interferes with the objectivity of patent evaluation. This study selects five commonly used subjective patent indicators that are directly related to the compilers of patent documents, which includes patent forward citations, patent family, four digit international patent classifications, patentees, and patent inventors. Through the progressive limitation of the three constraints of patentees, patent priority countries, and patent disclosure years, the correlation between the subjective patent indicators is compared. The research results show that under the control of progressive constraint conditions, the positive correlation between subjective patent indicators is increasingly strengthened as a whole and has strong controllability. Further verification shows that the direct compilers of patent documents can affect the results of patent indicator evaluation by controlling the subjective patent indicator data, thus interfering with the evaluation of patent quality. It is recommended that researchers carefully select multiple subjective patent indicators with strong correlation before using patent indicators to evaluate patent quality, and complete the correlation analysis and screening of subjective patent indicators in advance.*

Keywords: *Subjective patent indicators; Correlation control; Progressive constraint; Influence factor*

1. Introduction

In evaluating patents, scholars in the field of patent metrics often directly or indirectly use multiple indicators from patent literature data for analysis. In past studies, the selection and handling of these indicators varied according to the researchers and the materials used, leading to the development of a variety of patent indicator evaluation methods. The inherent correlation between these indicators often results in redundancy and high consistency of information, which affects the weight of the evaluation and subsequently the rationality of the evaluation results. While some studies have considered the correlation between indicators, they have not analyzed the conditions and reasons for the establishment of this correlation. Clearly, clarifying the correlation between indicators can provide a basis for simplifying the indicator system, increase the objectivity and authenticity of the evaluation, and improve the efficiency and accuracy of the evaluation. Therefore, it is of significant theoretical and practical importance to clarify the conditions that influence the correlation between various indicators and to explore the objective reasons behind the differences.

Due to historical limitations, early research did not fully consider the correlation of patent indicators. For example, Oh J H et al.[1] used patent indicators to study the impact on national technology levels without providing explanations for the selection and correlation of patent indicators, directly using the number of patent applications (NP, PGPA, PCPA), patent citations (CI, CII, TS, TCT), number of families (NF), total number of citations (NC), technology independence (TI), and revealed patent advantage (RPA) for evaluation. Harhoff D et al.,[2] while examining the patent value and the German Employees' Inventions Act, utilized 15 patent-related indicators without considering their correlation.

As research progressed, some scholars gradually recognized the impact of indicator correlation on evaluation. Sohn S Y et al.[3] systematically summarized previous research when evaluating patent value and listed the indicators used in research articles on certain patent indicators, finding that many of them had obvious correlations but were still included in the indicator system. Wang Qingshi[4] found that information redundancy between indicators generally exaggerates evaluation results, the degree of exaggeration depending on the method of integration.

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This disregard for the correlation between patent indicators is clearly unreasonable, because when there is a correlation between indicators, there is inevitably some degree of substitution between them, and the influence and redundancy of data are inevitable[5]. Subsequently, some scholars began to work on eliminating the impact of indicator correlation. Hu Yonghong et al.[6] categorized and filtered multiple evaluation indicators, adjusting the weight to build an indicator system that reduces the impact of correlation. Zhang Chongfu[7] used principal components for evaluation to reduce the impact of correlated indicators. Xu Xiangfa[8] proposed a method to eliminate the correlation of evaluation indicators.While these methods can reduce information redundancy to a certain extent, they do not seek the reasons for the existence of correlation between indicators.

Looking at the historical development of patent index evaluation, as patent data continues to improve and become more structured on a large scale, the construction of the patent index evaluation system has followed a path of pursuing a comprehensive index system. While this approach has maximized the use of data resources, it has also increased the workload, introduced illusions and confusion in expert judgments, raised the difficulty and cost of index judgment, and led to a reduction in index weight, distorting real information. The development history of patent indices, as studied and organized, has roughly undergone four stages. In the first stage, most research used original patent data and focused on theoretical research on methods. Patent index analysis research originates from the development of computer technology, massive patent data, and scientometrics. It is an applied research with an interdisciplinary nature. Utilizing patent indices to analyze the technological evolution, product competitiveness, and R&D activities of a particular industry was the main direction of early patent index metric analysis.[9][10] In the second stage, the focus was on application research based on practical needs. As research developed, more studies focused on the patent itself, using quantifiable indicators of patent literature data, such as citation volume, being cited volume, and patent literature quantity to evaluate the value or quality of patents.[11][12] Research evolved from focusing on a single indicator in a single industry to embracing diversified indicators and cross-industry research. Further processing of patent data resulted in new indicators, including the introduction of time variables and the establishment of relationships between patent index families like keywords, inventors, institutions, nationalities, and the impact across different industries, forming many new indicators, such as patent renewal data, geographical scope of patent protection, etc.[13][14] In the third stage, a research model combining theory and practice was constructed. Researchers chose more often to combine multiple data indicators for research analysis, forming an indicator system and analyzing evaluations and predictions. This included predictions for the future, trends in technological development, paths of knowledge spillover, prospects for commercial development, potential output levels of cooperation, with predictive research as the mainstream.[15][16] The fourth stage focused on denoising and enhancing patent index data, i.e., improving the accuracy and simplicity of patent index evaluation, researching the shortcomings of the index itself for specific research problems, and improving the reliability of analysis through methodological processing.[17][18] In addition, research on R&D activities and innovation outcomes has always been a popular research direction, which is closely related to the innovative activities that patents represent.[19][20][21]

The development of the above four stages reveals a general trend in the development of patent index research, i.e., increasing constraints, more indicators, and a higher level of complexity in the indicators. While previous research has done some work on screening indicators in the literature, there are few papers that focus on the correlation and influencing factors between different patent indices. As patent index research develops, this work is becoming more and more important. This paper discovers the pattern of stronger indicator correlation through conditions-based restrictions and explores the dominant reason for the strengthening of indicator correlation.

2. Methods and Data

Patent indices can be divided into subjective and objective indices based on whether they are controlled by the inventor. Subjective indicators include the number of claims, patent citations, number of drawings, number of IPC classifications, number of family patents, number of patent holders, number of inventors, etc. These indices are generally stable or controllable after the formation of the patent document. Objective indices refer to those that change over time after the formation of the patent document, including the number of times a patent is cited, whether it is cited by a patent examiner, the patent H-index, etc. The main indices studied in this paper are subjective patent indices.

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2.1. Methods

We used the patent data processing and analysis software Vantage Point to extract the data of the main patent indices processed in the above text. We then used Microsoft Excel to process the index data to form an index data table. Finally, we imported the data into SPSS software for correlation analysis. The correlation relationship of patent indices is mainly linear, so we used the Pearson correlation analysis method. Since we cannot determine the direction of the correlation (positive or negative) in advance, we used a two-tailed test. Generally speaking, after taking the absolute value, the larger the absolute value, the stronger the linear correlation. There is no correlation from 0 to 0.09, weak correlation from 0.1 to 0.3, moderate correlation from 0.3 to 0.5, and strong correlation from 0.5 to 1.0. The definition of the correlation coefficient in the calculation formula of Pearson's correlation coefficient is as follows:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2\sum_{i=1}^{n}(y_i-\bar{y})^2}} \tag{1}$$

In the formula, $\bar{x}$ and $\bar{y}$ respectively represent the mean values of variables *x* and *y*. x_i and y_i represent the *i*th observation of variables *x* and *y*. The calculation formula for the t-value in the correlation coefficient hypothesis test is as follows:

$$t=\frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \tag{2}$$

In the formula, r represents the correlation coefficient, n represents the sample observation quantity, and $n-2$ represents degrees of freedom. In the output of SPSS's correlation analysis process, only the probability P-value when the hypothesis is valid is provided.

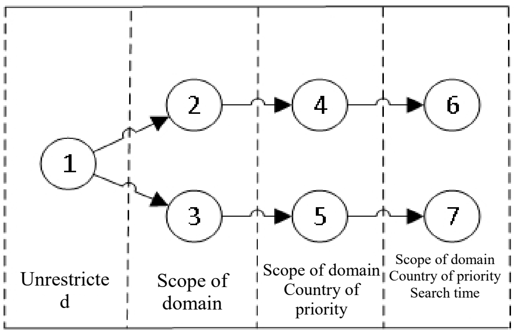

Figure 1: Progressive constraint patent indicator correlation analysis diagram.

The entire analysis process conducts a correlation analysis on patent indicators under seven different conditions. These correspond to the four processes ①②③④⑤⑥⑦ in Figure 1. Each pair of adjacent processes imposes a specific constraint. From left to right, they are to narrow down the scope of the patent field, to narrow down the scope of the patent field and reduce the countries of patent priority. Among them: Constraint on the scope of the domain: ①②, ①③; On the basis of the limited scope of the domain, the constraint on the country of priority: ②④, ③⑤; On the basis of limiting the domain range and country of priority, the constraint on the search time: ④⑥, ⑤⑦

2.2. Data

2.2.1. Selection of Subjective Patent Indices

From the main subjective patent indices, we selected those with structural features for correlation. This not only improves the operability of data processing in correlation research and ensures data availability, but also reduces distortion levels during data processing. The correlation indices selected include five: CT (citation times, number of patent citations), FMC (family member countries, number of family patents), IPC4 (international patent classification, number of 4-digit international patent classifications), PAC (patent assignee codes, number of patent assignees), IN (inventors, number of inventors).

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2.2.2. Selection of Constraint Conditions

The selected constraint conditions should define the subjective patent index dataset without changing the fundamental patent dataset. After being constrained, the new dataset should be a subset of the original dataset. Simultaneously, the constraint conditions should be able to constrain all patents in the database. Based on these principles, after several rounds of constraint condition training, we finally chose three constraints with more significant changes: patent field scope (patent assignee), country of patent priority, and patent publication time (year of patent application or publication). The specific meanings and operations of the three constraints are as follows:

Patent Field Scope: This is achieved by narrowing down the scope of the patent assignee. According to the Derwent patent assignee code, each patent document in the database has a designated four-letter patent assignee code, and a patent assignee code index is created. This is used to formulate a search for the patent assignee. Although we only chose Siemens and Hitachi (as mentioned in the patent database construction part), the downloaded patents widely involve collaborative patents. Using patent assignee codes to count the number of patent assignees and analyze patent collaboration is feasible.

Country of Patent Priority: This involves defining the country of patent priority, comparing the changes in index correlation, and exploring the impact of this constraint on the correlation of patent indices.

Patent Publication Time: On a yearly basis, different years are specified for patent retrieval. By comparing different index data, we can determine the impact of time on the correlation of patent indices.

2.2.3. Construction of Patent Database

This study uses the Derwent Innovation Index and Google Patent to download patent data. To meet the requirements of constraint conditions, it is necessary to construct a patent data source from multiple years, multiple companies, and with a large number of patent families. Therefore, the original overall patent data selected high-citation patents from Siemens and Hitachi, the two companies with the highest number of patents in the field of equipment manufacturing in the Derwent Innovation Index over the past 15 years. This data suits the patent data analysis under different constraint conditions. Moreover, both Siemens and Hitachi have their independent intellectual property institutions, which complete the patent compilation work for their respective companies, meeting the stability requirements of patent compilers in subsequent studies. We downloaded Siemens and Hitachi's patent data from the Derwent Innovation Index. For different data needs and under the limitation of variables such as field scope and retrieval time, we sorted by the latest citation frequency, downloaded related patents from Google Patent, and counted patent citation numbers.

3. Hypotheses and Validation

3.1. Research Hypotheses

The preliminary designs of the three hypotheses for the three constraint conditions are as follows:

Hypothesis 1: By narrowing the patent field scope, the overall correlation between each indicator becomes stronger.

Hypothesis 2: By reducing the number of patent priority countries, the overall correlation between each indicator becomes stronger.

Hypothesis 3: By concentrating the patent search time, the overall correlation between each indicator becomes stronger.

3.2. Hypothesis Validation

3.2.1. Validation of Hypothesis 1

Firstly, on the basis of no constraint conditions, the first 500 high-citation patents of Siemens and Hitachi are selected as the initial samples, and the correlation between the patent indicators is calculated. The correlation matrix between these six indicator variables is derived (see Table 1). From the results, there is a weak correlation between the patent indicators. The data in Table 1 shows that the greatest correlation relationship appears between IPC and IN, with the correlation exceeding 0.3, reaching a medium level, while the correlation between other indicators is relatively weak. However, other than the

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first column which did not pass the significance test (the main reason for failing the test is that the patent application time and patent citations were not constrained. The impact of constraining patent application time will be evidenced in the validation of Hypothesis 3), other indicators basically passed the significance test. Based on the analysis in Table 1, when the patent assignee is constrained, the data processing produces Tables 2 and 3, which analyze the correlation between the indicators from the perspectives of Hitachi and Siemens respectively.

Table 1: Correlation matrix of patent indicators without constraints.

N=500	CT	FMC	IPC	PAC	IN
CT	1				
FMC	-.018	1			
IPC	.019	.298**	1		
PAC	-.029	.123**	.286**	1	
IN	-.054	.043	**.301****	.274**	1

Note: *. Significant correlation at the 0.05 level, **. Significant correlation at the 0.01 level, same for tables below.

Table 2: Correlation matrix of hitachi's patent indicators.

N=500	CT	FMC	IPC	PAC	IN
CT	1				
FMC	.096* ↑	1			
IPC	.122**↑	**.350****↑	1		
PAC	.074	.230**↑	.197**↓	1	
IN	-.044	.004	.032	.054	1

The comparison between Table 2 and Table 1 shows that after merely constraining the patent assignee to be Hitachi, i.e., after narrowing the scope of the patent field, in the correlation matrix of all indicators, excluding those that did not pass the significance test, only one correlation decreases. The results show that the overall level of correlation has increased. In addition, when this patent assignee is constrained, the correlation between the number of inventors and other indicators is greatly affected, because the range of inventors is further reduced after the patent assignee is constrained. Overall, after the patent assignee is constrained, there is a trend of increasing correlation between patent indicators.

Table 3: Correlation matrix of siemens' patent indicators.

N=500	CT	FMC	IPC	PAC	IN
CT	1				
FMC	-.080	1			
IPC	-.025	**.356****↑	1		
PAC	-.019	**.352****↑	.289**↑	1	
IN	-.037	.192**↑	**.326****↑	**.423****↑	1

The comparison between Table 3 and Table 1 shows that after constraining the patent assignee to be Siemens, except for the first column CT, all other indicators have passed the significance test, and each correlation is stronger than that in Table 1. Overall, after the patent assignee is constrained, there is a trend of increasing correlation between patent indicators. From this, a comparison of the data in Table 1, Table 2, and Table 3 shows that Hypothesis 1 is established. By narrowing the scope of the patent field, the overall correlation between each indicator is stronger. Due to the single constrained limitation, the magnitude of the increase is not high.

3.2.2. Verification of Hypothesis 2

Based on the constraints in Table 2 and Table 3, the United States is designated as the country with priority for patents, resulting in the correlation tables shown in Table 4 and Table 5.

Table 4: Correlation matrix of patent indicators for hitachi with the united states as the country of priority.

N=203	CT	FMC	IPC	PAC	IN
CT	1				
FMC	.110*↑	1			
IPC	.140**↑	**.365****↑	1		
PAC	.077	.164**↓	.205**↑	1	
IN	-.040	.012	.047	.050	1

The comparison between Table 4 and Table 2 indicates that after restricting the analysis to the United States as a country of patent priority and excluding indicators that did not pass the significance test, the

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correlation of only one indicator slightly weakened. On the other hand, the correlation of other indicators strengthened, and there was an increasing trend in the correlation among patent-related indicators.

Table 5: Correlation matrix of patent indicators for siemens with the united states as country of priority.

N=263	CT	FMC	IPC	PAC	IN
CT	1				
FMC	-.006↑	1			
IPC	.026↑	**.347****↓	1		
PAC	.009↑	**.372****↑	**.324****↑	1	
IN	-.031↑	.196**↑	**.439****↑	**.468****↑	1

Comparing the data in Table 5 and Table 3, after simply restricting Siemens as the country of patent priority, excluding indicators that did not pass the significance test, among the correlations between each indicator, only one indicator showed a decrease in correlation. The other indicators all showed significant enhancement, and there are 4 with a correlation exceeding 0.3. This overall shows a trend of increasing correlation. According to the two different examples of Hitachi and Siemens, under the condition of specifying the country of patent priority, the overall correlation of patent indicators shows an upward trend, so Hypothesis 2 is also established. Because for a specific patent assignee, after restricting the country of patent priority, the overall strength of the correlation between various indicators becomes larger. And the degree of increase is more obvious compared to Table 1, because after two rounds of constraint restrictions, there is a cumulative effect of trend changes.

3.2.3. Verification of Hypothesis 3

Based on the constraints specified in Table 4 and Table 5, by limiting the patent search year, Table 6 and Table 7 of the indicator correlation tables are obtained.

Based on restricting the patent assignee to Hitachi, designating the United States as the country of patent priority, and the patent search year as 2006 (the time selection is based on the completeness and stability of the patent citation data and the richness of the number of patents, choosing ten years ago as the patent search year), excluding indicators that did not pass the significance test, comparing Table 6 and Table 4, the number of indicators (CT column) that passed the significance test in the first column has increased significantly, indicating the important impact of limiting time on the patent citation index. After setting the patent time, the correlation of 2 indicators slightly decreases, while the correlation of other indicators is enhanced to varying degrees, and there are 4 reaching moderate correlation. The number of indicators that passed the significance test also significantly increases. Overall, it can be concluded that after restricting the Country of Priority, the correlation between indicators is enhanced.

Table 6: 2006 patent indicator correlation matrix for hitachi with the united states as the country of priority.

N=149	CT	FMC	IPC	PAC	IN
CT	1				
FMC	.065↑	1			
IPC	.118*↓	**.337****↓	1		
PAC	.125**↑	.192**↑	.237**↑	1	
IN	.178**↑	**.413****↑	**.340****↑	**.488****↑	1

In comparison between Table 7 and Table 5, on the basis of restricting the patent holder to Siemens, country of patent priority to the United States, and patent search year to 2006, an increase in the number of indicators passing the correlation test is observed in the first column (CT column). This indicates that the time factor has a significant influence on the patent citation indicators. After excluding indicators that did not pass the significance test, two indicators showed a slight decrease in correlation, while the correlation of other indicators was enhanced to varying degrees. Overall, it can be concluded that limiting the patent search time strengthened the correlation among the indicators.

Synthesizing these two scenarios, based on the different examples of Hitachi and Siemens, under the condition of restricting the search time to 2006, the overall correlation of patent indicators presents an upward trend, thus confirming hypothesis 3. This is because, for different patent holders' patent samples, the changes in correlation show a consistent trend, that is, after the time limit is set, the overall strength of the correlation between various indicators increases. Moreover, the correlation is noticeably different compared to Table 1, with the reason being that after three rounds of restrictions, the trend changes become even more apparent.

From the analysis of the specific situation of the patent applicants, among the 500 patents of Hitachi,

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there are 310 patents with Hitachi as the first applicant, accounting for 62%; among the 500 patents of Siemens, there are 427 patents with Siemens as the first applicant, accounting for 85.4%. Could this be the main reason why Siemens' patent indicator correlation is stronger than Hitachi's? To verify this conclusion, based on Table 7, we extract 155 patents with Siemens as the first applicant, and conduct a correlation analysis on the four subjective indicators to obtain Table 8.

Table 7: Correlation matrix of 2006 patent indicators for Siemens with the United States as the country of priority.

N=197	CT	FMC	IPC	PAC	IN
CT	1				
FMC	.151*↑	1			
IPC	.034	**.383****↑	1		
PAC	.108	.257**↓	**.315****↓	1	
IN	.186**↑	**.392****↑	**.470****↑	**.706****↑	1

Table 8: Correlation matrix of patent indicators for 2006 patents with the United States as the country of priority and Siemens as the first applicant.

N=155	FMC	IPC	PAC	IN
FMC	1			
IPC	**.407****↑	1		
PAC	.262**↑	**.325****↑	1	
IN	**.401****↑	**.392****↓	**.717****↑	1

It can be observed that the correlation between each indicator is further enhanced, with only one indicator showing decreased correlation. This suggests that the more stable the patent compilers, the stronger the overall correlation of patent indicators. In our analysis of individual patent content, we discovered many habitual indicators. For instance, Siemens is often inclined to cite patents granted to their own company, and they tend to select patents with 20 claims more frequently; these are habitual practices. When reflected in large patent data sets, the correlation between patent indicators is quite strong.

It can also be noted that in the selected sample patents, the correlation of Siemens' subjective patent indicators is stronger. This is because a larger proportion of patents have Siemens as the first applicant, indicating that their patent literature compilers are more stable and focused. Comparing the inventors' data from Hitachi and Siemens, Siemens' inventors tend to be more consistent. This is the dominant reason why Siemens' patent indicator correlation is stronger than Hitachi's.

4. Conclusions and Implications

From an intuitive perspective, the reason for the trend of enhanced correlation is the increase in constraints, leading to enhanced agglomeration. When there are fewer constraints, the correlation between each indicator is relatively weak, and as the constraints intensify, the correlation between indicators gradually strengthens. Regarding patent holders, in the comparison of indicator correlation between Siemens and Hitachi, Siemens' overall patent indicator correlation is stronger. With constraints like narrowing the selected field, defining the country of patent priority, and limiting the retrieval time, the correlation of the filtered patent data indicators gradually strengthens.

From an extended perspective, the majority of Siemens and Hitachi's patent literature is decided by the company's own intellectual property institutions. As these institutions have mature patent application processes, the patents applied for naturally exhibit inertia in terms of content and format among other subjective indicators, thus resulting in stronger correlation. Among the selected patent indicators in the study, FMC, IPC, PAC, and IN are subjective determinative indicators that patent literature compilers can control, and their strong correlation has been verified in the previous analysis. Therefore, the homogeneity of patent literature compilers is an important factor in determining the strength of the correlation of subjective patent indicators. Further analysis revealed that patents with stronger indicator correlations have more stable patent compilation teams or processes, and the stability of the patent compilation team or process is positively correlated with the proportion of the first applicant being the company itself.

From a usability perspective, the data used in the study is generally applicable. That is, selecting a new patent data source and patent holder for indicator analysis, or selecting a new patent time period, will not change the general conclusions of the study. Researchers are advised to carefully select multiple subjective patent indicators with strong correlation, or to complete the correlation analysis and screening work of subjective patent indicators in advance when using patent indicators to evaluate patent quality.

Looking at improvements for future research, correlational analysis of sample patents must pass a significance level test. When comparing correlations, some indicators have not passed the significance test, and we can only choose to ignore these indicators, which can lead to certain comparative bias. The patent indicator data used in this paper only selects a few of the most commonly used indicators that can be processed using Vantage Point software, mainly researching the correlation of four subjective patent indicators. Therefore, in Tables 6 and 7, the correlation of indicators after limiting three constraints is not the highest level that can be achieved. If other indicators are considered, the final degree of correlation strength might be stronger, which is also the direction of future research work.

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