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Research on Efficient Construction Paths for Intelligent Coal Mines in China from the Configuration Perspective

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Abstract: The intelligent transformation of coal mines is an inevitable choice to promote the green transformation of energy and to achieve safety and efficiency in the industry. Exploring the path of its efficient construction is the key to realizing the construction of intelligent coal mines in China. To analyze the configuration paths for the efficient construction of intelligent coal mines, 17 typical coal-producing provinces in China were used as the research object of a fuzzy set qualitative comparative analysis (fsQCA), and five conditional variables, namely research funds, technical talent, government importance degree, national demonstration, and basic resource support, were selected from four levels (technology, organization, environment, and resources) based on relevant national data from 2019–2021, and multiple configurations as well as multiple driving paths for the construction of intelligent coal mines were discussed. We found that there are three configuration paths that will enable the construction of intelligent coal mines: a technology-driven path under the government's supervision, a path jointly driven by three-prongs, and a policy-driven path under the resource priority. The critical importance of the government is the common factor among the three driving modes. These research results can provide useful construction ideas for the construction of intelligent coal mines in different regions and enable provincial governments to carry out strategic combination actions according to local conditions to contribute to the efficient construction of intelligent coal mines and the green transformation of energy across the country.

Keywords: intelligent coal mine; efficient construction; energy transformation; configuration analysis; fsQCA

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1. Introduction

"Building a digital China" and "adherence to innovation-driven development" are important parts of China's outline of the "14th Five-year Plan" and Vision 2035 [1]. Since the release of the outline, the coal industry has followed the trend to implement the measures and comprehensively promoted the construction of intelligent coal mines with scientific and technological innovation as the core driving force. At the same time, accelerating the construction of intelligent mines is a useful way to achieve China's carbon peak and carbon neutrality targets, and it is a specific move to follow General Secretary Xi Jinping's ideas concerning ecological civilization and put into practice the notion that "green water and green mountains are golden mountains and silver mountains" [2]. Therefore, green, intelligent, safe, and efficient have become the current requirements for the sustainable development of modern mining and the inevitable choice for high-quality development. In March 2020, eight national ministries and commissions jointly issued the "Guidelines on accelerating the development of intelligent coal mines", so that the construction of intelligent coal mines could truly rise to the national level. In September 2020, the national intelligent coal mine on-site promotion meeting was held, which further defined the requirements for high-speed, high-efficiency, and high-quality intelligent coal mine construction. In December 2020, 70 coal mines in many provinces became the first batch of demonstration intelligent coal mines in the country, leading the construction of intelligent coal mines nationwide. As of the beginning of 2022, nearly 400 coal mines in China are carrying out intelligent construction, and 687 intelligent mining faces have been built. The intelligent mining faces with "few people for patrol and unmanned operation" are gradually moving towards normalization [3].

The intelligent coal mine is a multi-disciplinary and cross-integrated complex system of engineering that deeply integrates the new generation of information technology and coal development technology and equipment [4,5]. Although its development has gained rapid momentum in China, it is still in the cultivation and demonstration stage at present, there still being a lack of relatively complete and unified understanding [6]. The overall level of some areas is not high because of the constraints of the lagging of technological research and development, the lack of technical standards and specifications, insufficient equipment support, the lack of high-end talent, and other problems [7,8]. The overall level is not high, and there are still some core problems on the way to achieve comprehensive intelligence on which researchers are "stuck", and which need further research and exploration. There are still core problems of "bottlenecks" on the way to achieving comprehensive intelligence, and these need in-depth research and exploration.

Over the years, although the academic community has made clear the influencing factors behind the development of the construction of intelligent coal mines, they pay more attention to the theoretical construction and analysis stage of factors, such as technical analysis and policy advocacy, and lack understanding of the synergistic matching effect of multiple factors behind the differences in the intelligent construction achievements of coal mines in different situations. To deeply explore efficient construction paths, this research is based on previous research results and focuses on the current core problems. From the perspective of configuration, the method of fuzzy-set qualitative comparative analysis (fsQCA) is adopted. We explore the different combinations after the linkage matching of factors affecting the intelligent and efficient construction of coal mines and identify the path to improving the implementation of the construction of intelligent coal mines, thus summarizing the driving mode and exploration experience of the construction of intelligent coal mines in China and providing more targeted, realistic, and effective policies for the domestic construction of intelligent coal mines.

2. Framework Analysis and Model Construction

The road to the construction of intelligent coal mines in China is a long and arduous task which will require multi-party cooperation to fully combine technical personnel, environmental policy, and basic conditions so that the coal industry will always advance and achieve healthy and high-quality development [9].

Wang et al. [10] pointed out that strengthening the deep integration of the new generation of information technology and the coal industry is the future trend and emphasized the importance of scientific and technological innovation to the construction of intelligent coal mines. coal enterprises can cooperate with relevant colleges and universities, research institutes, etc., to strengthen the necessary core intelligent information technology and obtain complete sets of equipment, collaborate on the development and application of building modern "smart + green" and "security + efficient" coal mines and utilize systems to promote the digital and intelligent transformation of the coal industry. This will drive the structural reform of the energy industry, promote the low-carbon and green transformation of the energy industry, and finally achieve the high-quality development of the energy industry. Kang et al. [11] suggest that the coal industry needs to build a high-quality talent team and ensure that the training of high-skilled talent in the coal industry develops synchronously with project construction. The government has also encouraged school–enterprise cooperation to train high-skilled personnel in the intelligent coal mines, and, at the same time, increased the intensity of intelligent coal mine training, driving the independent development of intelligent coal mine-related technical personnel and optimizing the development of systems of technical management. Wang [12] has stated that the Chinese government has formulated and promulgated a series of policies and regulations to strengthen the production and safe supervision of intelligent coal mines, and its construction results reflect the strong driving force of government organizations. The "guidance on Accelerating the intelligent development of coal mines" [13] will also strengthen the coordination of departments and enable them to accelerate the improvement of intelligent coal mine-related regulations, policies, and standards. As one of the important guarantee measures of intelligent coal mine construction, it is very important to provide priority support for the acceptance of intelligent coal mine demonstration. The state has fostered a number of coal enterprises with the advantages of intelligent intellectual property rights in coal mines by setting up special working classes and strengthening the protection of intellectual property rights [14] in order to assume the role of "leader", create a positive and healthy development environment, and accelerate the high-quality and efficient development of the coal industry. Based on the traditional resource endowment theory, Luo et al. [15] analyzed and discussed technology level and natural resource endowment as influencing factors in the transfer trend of China's energy-intensive industries. In the "Intelligent Coal Mine Acceptance Scoring Method" [16], the conditions of coal mine resource endowment were also taken as the classification basis of intelligent coal mine construction conditions. Coal mines were comprehensively evaluated according to the classification results and the corresponding score index, indicating the important position of resource level. In addition, although coal mine safety management, production, and operation, among other problems, will also hinder the construction of intelligent coal mines to a certain extent [17,18], obviously, in the construction stage, scientific research and innovation, technical personnel, the allocation of government attention, the development environment, and resource endowment have more serious implications for the construction of intelligent coal mines.

To sum up, this paper introduces the fsQCA method and proposes five variables from the four levels of technology, organization, environment, and resources to build an analysis framework of the factors influencing the intelligent and efficient construction of coal mines (Figure 1) and analyzes and explains each influencing factor.

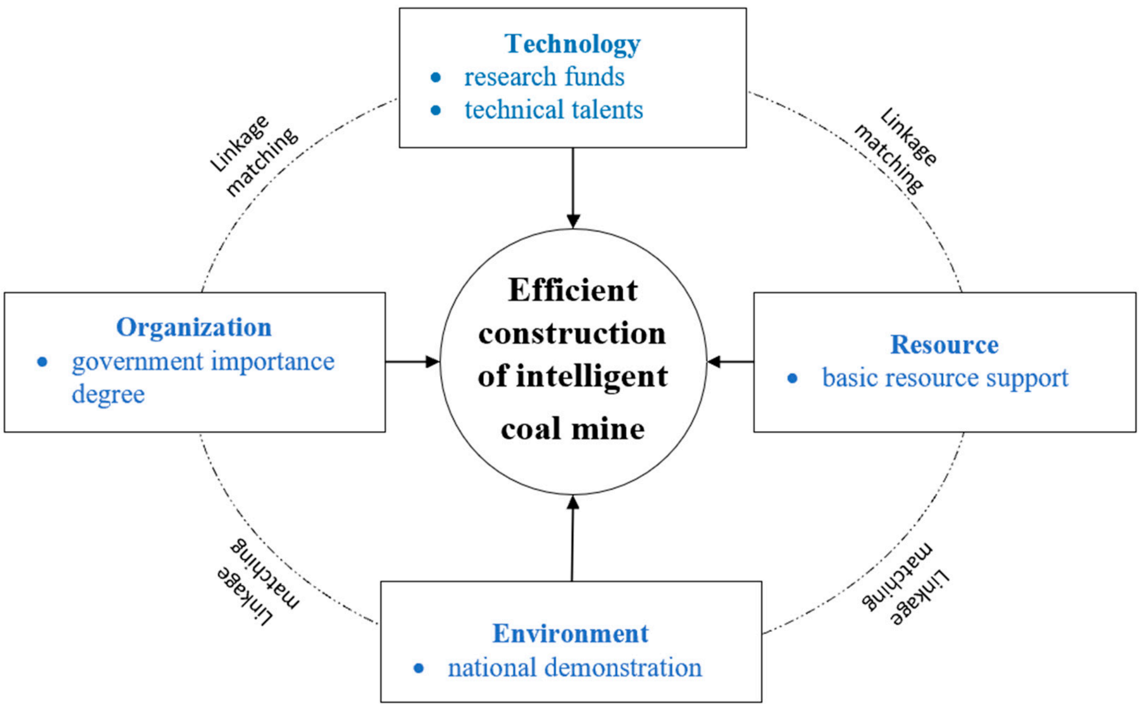

Figure 1. Analysis framework of factors influencing the construction of intelligent coal mines.

(1) Technology

The technical level mainly includes research funds and technical talent. Scientific and technological innovation is the internal driving force for development [19]. The technological innovation of the intelligent development of coal mines is to deeply integrate contemporary front-end technology and coal mining technology so as to realize the construction of intelligent coal mines [20]. In order to realize the real intelligent transformation of coal mines, it is necessary to fully adopt and integrate the advanced technology and equipment of relevant industries at home and abroad [21], increase research and development investment in China's intelligent coal machine equipment, and further optimize and improve the level of national intelligent coal machine equipment. Therefore, it is not unreasonable to take the research and experimental development (R & D) fund, which is commonly used to measure the intensity of scientific and technological resources allocation, as a technical index to evaluate the performance of the construction of intelligent coal mines [22]. Intelligent coal mines will be unmanned, but not entirely, because high-tech and sophisticated information technology talent is indispensable [23]. The development of the Internet industry is closely related to the intelligent development of coal mines. The coal industry urgently needs compound talents to ensure the sustainable development of high-tech development [8]. It can be seen that intelligent construction will deeply root a new generation of information technology, high-end intelligent equipment, and high-level compound talent in the industry and enable the coal industry to transform from a traditional resource-dependent and labor-intensive industry into a technology-intensive and knowledge-intensive high-tech industry. Solving the problems of technological innovation and the shortage of professional talent is the key factor to breaking through the constraints on the intelligent construction and development of coal mines [24]. At the technical level, this paper is mainly focused on research funds and technical personnel.

(2) Organization

The organizational level mainly refers to the degree to which the government's role is important. The current situation of intelligent coal mine technology shows that the government's guidance and support will promote the diffusion of digital technology [25]. Therefore, intelligent coal mines need to be policy-oriented and pool the joint forces of government, academic, industrial, and financial communities [17]. If the incentive policies are weak, the procedures are complex, and the conditions are strict, the driving force for coal enterprises to adopt high-tech equipment will be insufficient [26]. Before and after 2020, intelligent coal mine policies at the provincial level have been planned in terms of construction objectives, contents, acceptance grading, and even standard formulation, which has played an irreplaceable role in promoting the research and construction of intelligent coal mines [17]. Although there are slight differences in the starting points and implementation progress of intelligent coal mines, it can be seen that the government's high degree of importance and strong support will only increase the construction results in this area. The degree of attention paid by the provincial and regional governments has great significance for promoting the sound development of intelligent coal mines. Therefore, at the organizational level, this paper focuses on the degree of government emphasis.

(3) Environment

The environmental level mainly refers to the national demonstration. The proposal of the list of the first batch of demonstration intelligent coal mines in China has promoted the construction of demonstration intelligent coal mines under different geological conditions. Building a demonstration intelligent working face and realizing the construction achievement of "few people in the working area and no one in the dangerous area" will be a strong demonstration for coal mining enterprises in various provinces and regions [27]. It can be seen that adhering to the principle of combining typical demonstration with comprehensive promotion is a successful strategy and will promote the technological progress and development of coal mines [28]. The national demonstration could be one of the factors to speed up the construction of intelligent coal mines. Consequently, at the environmental level, this paper focuses on the national demonstration.

(4) Resources

The resources level mainly refers to basic resource support. The resource endowment and development foundations of the 23 coal-producing provinces in China are uneven [29]. Some areas lack basic coal resources, which has become a "pain point" restricting the intelligent development of local coal mines [30]. In this regard, some scholars have proposed that the focus of mine construction work should be to comprehensively consider the basic resource endowment and other local conditions of mines in various places [31], determine a reasonable level of construction investment, and adjust measures to local conditions in order to accurately implement the policies. Considering the support of basic resources has also become one of the factors in the performance evaluation of intelligent coal mine construction. Hence, at the resource level, this paper focuses on basic resource support.

3. Research Methods and Data Construction

3.1. Research Methods

In this paper, a qualitative comparative analysis (QCA) method based on set theory is used to try to analyze the multiple and complex mechanisms behind the construction of intelligent coal mines in China from the perspective of configuration. The QCA method proposed by Charles C. Ragin is suitable for the analysis of small and medium-sized samples, to determine the causal mechanism of the research subject, and to identify multiple concurrent factors and their influence mechanisms [32,33]. At present, the QCA method includes crisp-set QCA (csQCA), fuzzy set QCA (fsQCA), and multi-value set QCA (mvQCA). Unlike csQCA, fsQCA introduces fuzzy mathematics by allowing values between 0 and 1 so that the value of the fuzzy set is no longer limited to a binary decision, the membership can be more accurately divided into variable ranges [34], and the influence of the change in conditional variables at different levels and degrees can be observed. A value of 1 means "fully affiliated with a set", a value close to 1 means strongly affiliated, a value less than 0.5 but greater than 0 means weakly affiliated with the set, and 0 means not affiliated with a set at all. The values of some conditional variables in this study require the non-binary assignment method, so the application of fsQCA is more in line with the actual situation [32,33].

3.2. Data Resource and Sample Selection

From the "China City Statistical Yearbook" of 2021 and the "China Energy Statistical Yearbook" of 2021, data such as industrial R & D funds, the number of employees in the IT industry, and raw coal production are selected. In combination with government work reports on the official websites of the national and provincial people's governments, the Bureau of Energy, and other official information on the Internet (news, conferences, etc.), data related to the construction of intelligent coal mines are collected as variable data sources.

On the condition that sample homogeneity, diversity, and data availability requirements were all met [35,36], this study excluded 6 provinces, including Chongqing (which withdrew from coal mining in 2021) and Yunnan Province (data missing) from the 23 coal producing provinces in China and selected 17 provinces as the research objects.

3.3. Variable Measuring

The condition variables and outcome variables are measured (Table 1).

Table 1. Variable settings and data sources.

Variable Type			Measurement Index	Data Source
Conditional variables	Technology	Research funds (FUND)	The R & D fund of industrial enterprises above the designated size in the mining industry	China City Statistical Yearbook
		Technical talent (TAL)	The number of IT industry employees	China City Statistical Yearbook
	Organization	Government importance degree (IMP)	2019–2021 annual government work reports and "intelligent coal mine" construction	Official government website
	Environment	National demonstration (DEM)	The number of local mines enrolled in "The list of the first batch of intelligent demonstration coal mines in China"	Official government website
	Resources	Basic resource support (RES)	Continuous increase in raw coal production in 2019–2021	China City Statistical Yearbook, China Energy Statistical Yearbook
Outcome variable	Effect of coal mine intelligent construction (ECM)		The completion of intelligent working faces in coal mines	Official government website, official information on the Internet

Condition variables: ① Research funds (FUND). The R & D fund of industrial enterprises above the designated size in the mining industry in each province in 2020 is used as the measurement index for research funds, and data from the yearbooks are collected directly to provide initial values for subsequent data calibration; ② Technical talent (TAL). The IT industry employees of each province in 2020 is adopted as the measurement index for technical talent, and data from the yearbooks are collected directly to provide initial values for subsequent data calibration; ③ Government importance degree (IMP). The number of occurrences of "intelligent construction/promotion of coal mines" in the work reports, documents, and policies of provincial governments from 2019 to 2021 is adopted. The value is 0 for no occurrence, 0.33 for one year, 0.67 for two years, and 1 for all three years; ④ National demonstration (DEM). "The list of the first batch of intelligent demonstration coal mines in China" is adopted as the standard to screen the coal mines in various provinces and regions, and the results of the statistics list are used directly as initial values for subsequent data calibration; ⑤ Basic resource support (RES). The raw coal output from 2019 to 2021 is adopted. If the raw coal output increases for three consecutive years, the value is 1, and otherwise it is 0.

Outcome variable: effect of coal mine intelligent construction (ECM). According to the development goals of intelligent mines, the comprehensive realization of intelligent working faces will be taken as the main achievement goal by 2025, and intelligent mining is one of the core systems of intelligent coal mines [20]. Therefore, the completion of intelligent working faces in coal mines is selected as the measurement index of its construction effect to investigate the complex causal relationship behind the intelligent and efficient construction of coal mines at this stage. The specific indicator data are from the work reports of the provincial people's governments, the Bureau of Energy, and other official websites, as well as official information on the Internet. Hence, the value of the provinces and regions where the existing intelligent working faces have been built and put into use is 1, and otherwise it is 0.

3.4. Data Calibration

The original data were calibrated, each variable was treated as an independent set, and the set was given a membership. Drawing on previous studies, the data were converted to fuzzy set affiliation values using the direct calibration method. Considering the similarities between the selection of variables in the study of Meng et al. [36] and in this study, and the fact that previous studies on smart cities are most relevant to the study of smart coal mine construction cases, the calibration standard for the flat crossover point of the sample data was set as 0.5 quantiles, the calibration standard for completely unaffiliated was set as 0.25 quantiles, and the calibration standard for completely affiliated was set as 0.75. In addition, the value of the conditional variable of the IMP was continuously distributed between 0 and 1, so there was no need for recalibration (Table 2).

Table 2. Calibration of the condition and outcome variables.

Condition and Outcome Variables	Membership Point		
	Full Membership	Intermediate Point	Full Non-Membership
FUND	195,025	79,252	22,322
TAL	17.35	8.5	4.5
DEM	5.5	2	0
RES	1	-	0
ECM	1	-	0

4. Data Analysis and Discussion of Results

4.1. Univariate Necessity Analysis

A dataset file in .csv format was added to the fsQCA 3.0 software for calibration and run through the fsQCA3.0 software to generate truth tables to test the consistency and coverage of a single conditional variable and its non-aggregate ("~" means non-aggregate). The consistency test is mainly used as the test standard of necessary conditions. If the consistency is higher than 0.9, the conditional variable is considered to be the necessary condition of the outcome variable [32]. The coverage rate mainly judges the explanatory power of the conditional variables or combinations of the outcome variables. The higher the coverage rate, the stronger the explanatory power of the conditional variables to the outcome. The consistency of each condition variable after the test is lower than 0.9, which indicates that the effect of the construction of intelligent coal mines is the result of the cooperative action of multiple factors, and there is a complex causal mechanism which requires condition configuration analysis (Table 3).

Table 3. Test of condition variables.

Condition Variables	Consistency	Coverage Rate
FUND	0.663636	0.900123
~FUND	0.336364	0.416198
TAL	0.516364	0.716267
~TAL	0.483636	0.586549
IMP	0.758182	0.833167
~IMP	0.241818	0.380544
DEM	0.722727	0.963636
~DEM	0.277273	0.348571
RES	0.272727	1.000000
~RES	0.727273	0.571429

4.2. Condition Configuration Analysis

The configuration analysis aims to explain the sufficiency of the different configurations formed by each condition variable to produce the result variable. At present, the consistency threshold used to measure sufficiency is often different due to the differences in research situations. In accordance with the suggestion of Fiss [37], the consistency threshold is determined to be 0.8 and the frequency threshold is determined to be 1 to obtain a complex solution, a parsimonious solution, and an intermediate solution. Referring to previous studies, the condition variables that appear simultaneously in the intermediate solution and the parsimonious solution are regarded as core conditions, and the condition variables that appear only in the intermediate solution are regarded as edge conditions. Each condition variable interacts to form three condition configurations, and the overall consistency is higher than 0.8, indicating that these three configurations can be regarded as a sufficient condition combination for the efficient construction performance of intelligent coal mines. The overall coverage can effectively explain nearly 63.1% of cases (Table 4).

Table 4. Configuration analysis of the effect of the construction of intelligent coal mines.

Conditional Variables	Configuration	Technology-Driven under the Government's Supervision	Jointly Driven by Three Prongs	Policy-Driven under the Resource Priority
		Configuration 1	Configuration 2	Configuration 3
Technology	FUND	●	●	⊗
	TAL	•		⊗
Organization	IMP	●	●	•
Environment	DEM		●	●
Resources	RES	⊗		⊗
	Consistency	0.9412	1	0.9286
	Original coverage rate	0.2764	0.1982	0.1773
	Unique coverage rate	0.2555	0.1982	0.1564
	Overall consistency		0.9679	
	Overall coverage rate		0.6309	

Note: ● indicates that the core conditions exist and have a great impact on the outcome variables; • indicates that the auxiliary conditions exist and have little impact on the outcome variables; ⊗ indicates the absence of the core conditions.

4.3. Results and Discussion

Configuration 1 (FUND*TAL*IMP*~RES) indicates that the research funds and the government importance degree jointly exert influence on this path, and that technical talent play an auxiliary role. Therefore, this path is named the technology-driven path under the government's supervision. This path can explain about 27.6% of intelligent coal mine construction cases, of which about 25.6% can only be explained by this path.

Configuration 2 (FUND*IMP*DEM) indicates that in addition to the research funds and the government importance degree, the national demonstration has also become a core condition, and this path can be called the path jointly driven by three prongs. This path can explain about 19.8% of the intelligent coal mine construction cases, and about 19.8% of the cases can only be explained by this path.

Configuration 3 (~FUND*~TAL*IMP*DEM*~RES) indicates that the national demonstration plays a core role, supplemented by the government importance degree, and this path can be called the policy-driven path under the resource priority. This path can explain about 17.7% of the intelligent coal mine construction cases, and about 15.6% of the cases can only be explained by this path.

Based on the analysis results, three configuration paths for the intelligent and efficient construction of coal mines in China are summarized, and the three types of configuration paths are described in detail by selecting cases with outstanding explanatory effects for each configuration (Figure 2).

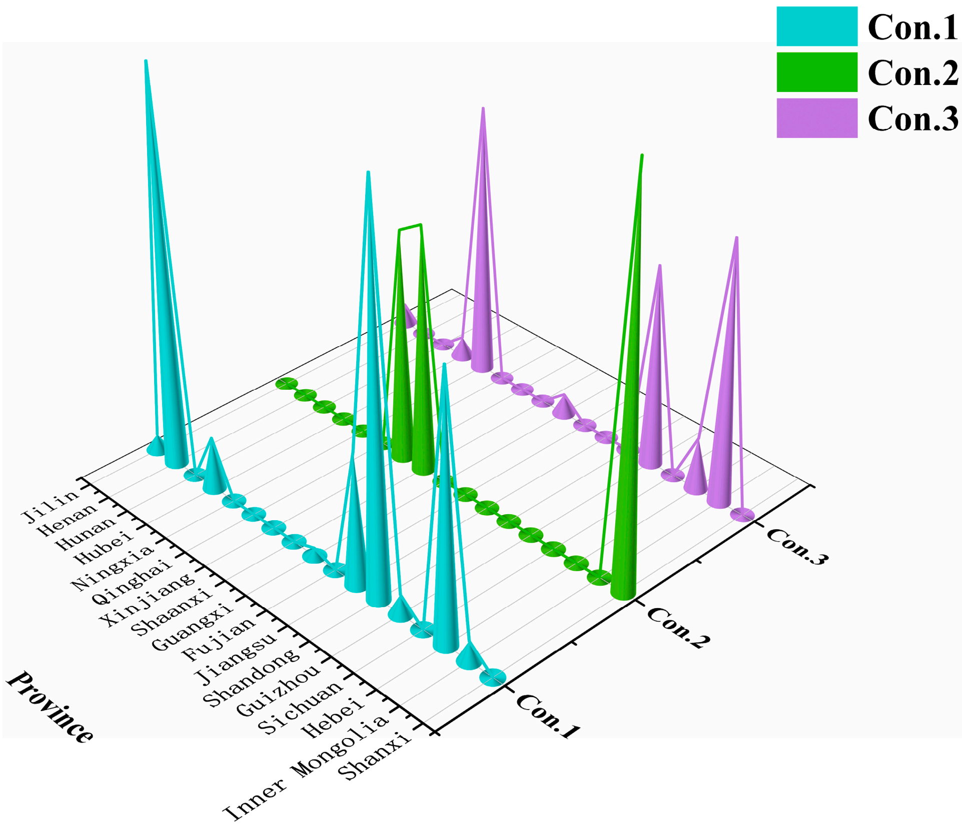

Figure 2. Explanatory cases of three configurations.

(1) Technology-driven path under the government's supervision

This path type is reflected in Configuration 1, with Shandong Province as a typical representative.

Shandong Province is one of the coal-producing provinces with large coal-production enterprises, such as Yankuang Group. According to data from the Shandong Coal Industry Association, the total output value of the provincial coal enterprises in 2020 was CNY 710 billion, accounting for 9.7% of the provincial GDP. Moreover, in 2020, the R & D funds of industrial enterprises above the designated scale in the mining industry of Shandong Province ranked first among the research cases. In addition, Shandong Province is located in a region where the distribution of technology-based enterprises is more advantageous, and the number of technology-based enterprises in this province is behind only to Guangdong, Jiangsu, Zhejiang, Beijing, and Shanghai, of which only Jiangsu Province is a coal-producing province, which shows that Shandong Province is rich in information technology-based talent and possesses one of the important foundations for the intelligent and efficient construction of coal mines. Furthermore, the Shandong provincial government attaches great importance to the intelligent construction of local coal mines and closely follows the national intelligent coal mine development plan. Since 2019, it has issued the "Implementation plan of intelligent coal mine construction in Shandong Province" and the "Implementation opinions on accelerating the intelligent development of coal mines in Shandong Province", among other policies. As a result, Shandong Energy Group, the largest coal company in China, completed hundreds of intelligent working faces in September 2020.

Clearly, regions with high government priority and abundant technology and talent are well placed to achieve the efficient construction of smart coal mines, but insufficient resource endowment may be one of the factors limiting the further development and growth of smart coal mines in such regions.

(2) Path jointly driven by three prongs

The path jointly driven by three prongs is reflected in Configuration 2 and is typified by Shanxi Province. Although it is located in the central plains, where the science and technology are not outstanding, its R & D funds are quite advantageous for the inland, and one of the reasons for this is that it is based on the featured coal industry. Since 2017, the 5G Intelligent Mine Alliance was established by the Global Headquarters of Huawei Coal Mine Corps, China Mobile, and their partners, and some local enterprises (such as Jingying Link and Keda Automation Control) are deeply engaged in the field of intelligent coal mines and have continued their efforts to again make Shanxi the focus of the national coal industry, consolidating and strengthening the foundation of scientific research and innovation.

The Shanxi provincial government has cooperated with local leading enterprises many times, taking the lead in introducing relevant policies and standards, establishing an expert base, and holding meetings to promote the construction of intelligent coal mines to strengthen the featured industry of the province. Taking Shanxi China Coal Pingshuo Group as an example, under the guidance of the government, the Group actively explored the unmanned and intelligent development of mines, and while carrying out the construction of a 5G and driverless intelligent mine project, it prepared the first provincial-level intelligent surface coal mine construction code, namely the "Code for construction of intelligent surface coal mine", as per Shanxi provincial local standard, which provides a reference for the implementation of large-scale industrial technology (Table 5).

Table 5. Summary of policies and activities related to intelligent coal mine construction in Shanxi Province.

Date	Related Policies and Activities
8 May 2020	The Shanxi Provincial Energy Bureau, the Provincial Development and Reform Commission, and the Coal Mine Safety Supervision Bureau studied and formulated the "Implementation opinions of intelligent coal mine construction in Shanxi Province"
8 December 2020	The Shanxi Provincial Energy Bureau issued the "Evaluation method for the intelligent construction of coalmines in Shanxi Province (Trial)" and the "Basic requirements and scoring methods for the intelligent construction of coalmines in Shanxi Province (Trial)"
17 December 2020	The provincial government formulated the "2021 provincial work plan for further promoting the intelligent construction of coalmines"
22 December 2020	The on-site promotion meeting of intelligent construction of coalmines in Shanxi Province hosted by Shanxi Provincial Energy Bureau and undertaken by the Jinneng Holding Group was held in Tashan Coalmine
26 January 2021	The Shanxi Provincial Energy Bureau released the "List of mining faces for intelligent construction of coalmines in Shanxi Province 2021"
9 June 2021	The Shanxi Provincial Energy Development Center issued the "Notice on publicizing the list of experts to be selected for intelligent coalmine construction in Shanxi Province"
26 January 2022	The Shanxi Provincial Energy Bureau issued the "Guidance manual for intelligent construction of coalmines in Shanxi Province"
27 January 2022	The Shanxi Provincial Energy Bureau issued the "2022 work plan for further promoting the intelligent construction of coalmines in Shanxi Province"

Moreover, 1/7 of the mines on the list of the first batch of demonstration intelligent coal mines in China are located in Shanxi Province. Both the direction of media and public opinion and the tendency of government resource allocation have played an obvious leading role in the intelligent construction of local coal mines, which has laid a solid ideological and material foundation for promoting the construction of intelligent coal mines. By the end of 2021, Shanxi Province had built 10 intelligent coal mines and 328 intelligent mining faces, and its intelligent mining of coal mines ranks at the forefront in the country.

This driving mode is suitable for provinces and regions with both rigid and flexible conditions. Due to the sufficient scientific research funds, high government importance degree, and fast action, it is often easier for Shanxi province to achieve the goal of the intelligent and efficient construction of coal mines than other provinces and regions.

(3) Policy-driven path under the resource priority

The policy-driven path under the resource priority is reflected in Configuration 3, and the Inner Mongolia Autonomous Region is selected as a typical representative.

Compared with Hebei, Henan, and Jiangsu, Shaanxi, Shanxi, and Xinjiang provinces in Configurations 1 and 2, the development level of the Inner Mongolia Autonomous Region in terms of its economy, talent, science, and technology is not outstanding. Nevertheless, after the Fourth Plenary Session of the 19th CPC Central Committee in 2019, the Inner Mongolia Autonomous Region Government issued the "Implementation opinions on accelerating the intelligent construction of regional coal mines", putting forward the construction plans for 2021, 2025, and 2035, and has continuously strengthened the implementation of construction. "The acceptance measures of intelligent construction of coal mines in Inner Mongolia (Trial)" was introduced, and the acceptance standards for the construction of intelligent coal mines were released. Industry experts were invited to formulate and complete "The three-year action plan for promoting intelligent construction of coal mines in Inner Mongolia Autonomous Region" and clarify the guiding ideology. Several training sessions, seminars, and symposiums on the construction of intelligent coal mines were held. Top domestic experts were invited to deliver lectures, providing technical guidance and accurate training for the smooth advancement of intelligent construction.

Furthermore, 11 coal mines in the Inner Mongolia Autonomous Region have been selected for the list of the first batch of demonstration intelligent coal mines in China, thereby providing an unshakable demonstration playing and a leading role in the intelligent construction of local coal mines. To a great extent, this has mobilized the enthusiasm and action of the construction and development forces of the whole region. The Inner Mongolia Autonomous Region has built many intelligent working faces and has even been in the leading position in China many times. Seven coal mines, including the Madi Liang coal mine, have reached the acceptance standard for intelligent coal mines.

It can be seen that although the overall strength of Inner Mongolia is relatively modest among the coal-producing provinces, and although the coal mine situation is complex, the local government adheres to the spirit of the central government and accurately implements policies, laying a good foundation for the intelligent construction of local coal mines and exploring a development path. This shows that economically backward areas are often subject to various influences, and it is difficult for the technical elements to be rapidly improved within a short period. However, the government can also promote development by attaching great importance to the construction process.

5. Conclusions

5.1. Conclusions

To summarize the beneficial effects of the intelligent and efficient construction of coal mines in China under different paths, the fsQCA method is applied for the first time in this paper to conduct a conditional configuration analysis of the intelligent construction of coal mines in 17 coal producing provinces in China and to explore the effects of technology, organization, environment, and resource factors on the construction of intelligent coal mines in China. The specific research conclusions are as follows.

(1) On the whole, the intelligent and efficient construction of coal mines has complex causality. The development of a single technology, organization, environment, or resources factor cannot reflect the necessary conditions for the intelligent and efficient

construction of coal mines. That is to say, the high efficiency of the intelligent construction of coal mines is the result of the interaction of multiple factors.

(2) The configuration analysis of the conditions for the intelligent and efficient construction of coal mines has generated three configuration results: technology-driven under the government's supervision, jointly driven by three prongs, and policy-driven under the resource priority, all of which are necessary conditions for the intelligent and efficient construction of coal mines, and which each achieve the effect of "achieving the same goal through different paths".

(3) Due to the technical conditions, development environment, and resource endowment of various provinces and regions, the implementation of the construction of intelligent coal mines differs from region to region. However, the results of the configuration analysis show that the three paths are inseparable from the government's importance degree. It can be seen that the government's support is of great significance to the sustainable and intelligent development of coal mines and provides practical ideas for provinces and regions where the intelligent construction of coal mines is in a backward state.

(4) China's geographical diversity and complex coal conditions have led to different paths of intelligent coal mine construction in the coal-producing provinces. To begin with, the technology factor is the key advantage in achieving smart coal mining in areas where the technology is developed but the underlying resources are scarce. Second, well-funded and exemplary regions are the focus of intelligent coal mine construction in China due to their own complete conditions. In addition, government and industry trends are an important guide to the construction of local smart coal mines in regions where overall strengths are more underdeveloped.

5.2. Recommendations

In light of the above conclusions, we put forward the following suggestions for the construction of intelligent coal mines in the future.

(1) The intelligent construction of coal mines is a long-term and complex affair, and it cannot be accomplished overnight. The configuration path of the influencing factors behind it may also change the focus of different construction stages. The academic community must continue its in-depth exploration and cooperate with the government, enterprises, and other construction organizations to form a complete intelligent coal mine construction and development chain.

(2) The various provincial and regional governments should strengthen the coordination among the factors of technology, organization, environment, and resources, systematically and comprehensively consider the factors influencing the intelligent construction of coal mines, and cooperate with the relevant enterprises to formulate development strategies that suit local conditions by taking into account the differences in the scientific and technological foundations, environmental resources, and conditions in different regions.

(3) Since the intelligent and efficient construction of coal mines cannot be separated from the government's supervision, the provincial and regional governments should fully recognize the necessity and importance of developing the construction of intelligent coal mines and support the comprehensive construction of intelligent coal mines to accelerate the realization of China's carbon peak and carbon neutralization targets.

(4) In cases of limiting environmental conditions and technical conditions, the government should pay close attention to the construction of intelligent coal mines, which is also an important way to improve construction efficiency.

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