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Research Article

Competitiveness of Coal Chemical Industry Based on Diamond Model

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Coal chemical industry is one of the main ways of clean coal utilization. The orderly and regulated development of coal chemical industry is an important task in supply-side reform of China's coal industry. China's coal chemical industry has a good development foundation and great potentials and has taken the lead in some fields globally. Based on the six elements of the diamond model and qualitative analysis, an evaluation index system is constructed. The weights of different indexes are obtained through the entropy weight method, and the influence of the six elements on the competitiveness of the coal chemical industry is analyzed. The results show that among the six elements of the diamond model, horizontal competition delivers the greatest impact on the competitiveness of the coal chemical industry, followed by production factors, related and supportive industries, and the government, with demand conditions showing the least impact on the competitiveness of this industry.

1. Introduction

Over recent years, with continued development of economy in China, the gap between oil supply and demand has kept expanding; with insufficient self-produced oil, the imported oil has continued to grow rapidly. At present, China's oil import and consumption are ranked the first and second in the world, respectively, with a continuously upward trend. This situation poses a huge threat to China's energy security. However, with increased investment in technology and innovation, China's scientific and technological strength has been raised rapidly. Now, China stands in the world's leading position in coal chemical technology, and it is possible to manufacture relatively scarce petroleum resources from its abundant coal resources. This industry would help the sustainable utilization of energy and mitigate environmental pollution caused by coal burning, while relieving the dependence on imported oil. Therefore, this industry will be an important development direction of China's energy industry in the next two decades, and it is essential to analyze its competitiveness. To analyze the competitiveness, the essay tries to apply Porter's diamond model which is raised to find out the sources of an industry's competitiveness. In this way, analyze direction will be found with the help of the model's six elements.

2. Literature Review

At present, scholars' research on the competitiveness of coal chemical industry have done from two aspects. First, they use the existing theoretical models for analysis. According to the SWOT model (S refers to strengths, W refers to weakness, O refers to opportunities, and T refers to threats), they find that the competitive advantages of coal chemical industry include the following: abundant resources, complete varieties, low prices, leading technologies, regionally clustering development, guaranteed market demand, and optimistic industry prospects [1–3]. According to Michael Porter's "diamond model" theory, some scholars find that CTL which is short for coal-to-liquid is more competitive than oil in terms of market demand conditions, government, and technical feasibility [4, 5]. And from the perspective of regional comparison, this theory is used for evaluation in six aspects, including resource endowment, market competitiveness, infrastructure, economic benefits, environmental impact, and policy support, finding that the coal chemical industry in Inner Mongolia and Shaanxi Province has the strongest comprehensive competitiveness [6–8]. In addition, the scholars have analyzed and compared the coal chemical industry with other industries. Through the comparison between the new coal chemical technologies with the traditional ones has concluded that the former is more competitive in terms of energy consumption, resource utilization of "three wastes," as well as "zero" emissions and CCS namely carbon capture and storage [9–11]. The comparison between the coal chemical industry and other industries shows that the former is more competitive in water resource utilization, pollutant emission and treatment, and carbon dioxide capture; and in terms of economic benefits, CTL and coal-to-olefins would become more competitive than petroleum products when Brent oil prices exceed US$80/barrel and US$50/barrel, respectively [12, 13]. A comparison within the modern coal chemical industry which has realized industrialized production shows that coal-to-olefins have the best economic efficiency [14, 15]. Compared with the petrochemical industry, the coal chemical industry has weak competitiveness in terms of project scale and investment, but maintains certain competitiveness in terms of product characteristics and cost [16, 17].

From the literature review, it can be found that the competitiveness of coal chemical industry has been analyzed from the perspectives of SWOT model, Porter's diamond model, and competitiveness comparison with related industries. However, in the process of Porter's diamond model analysis, existing research have only explored competitiveness evaluation qualitatively based on the indexes of the diamond model, but with no quantitative research conducted. Therefore, in the following research, this study will construct an evaluation index system from the perspective of the six elements of the diamond model, so as to quantitatively measure the influence of the six elements on the competitiveness of the coal chemical industry by calculating the weights of different indexes.

3. Construction of Competitiveness Evaluation Index System for China's Coal Chemical Industry

3.1. The Basis of Constructing the Evaluation Index System. According to the diamond model, six elements, i.e., production factors, demand conditions, related and supportive industries, corporate strategies, structure and horizontal competition, and opportunities and governments, work together to determine whether a particular industry is competitive [18–20]. Of the six elements, the first four are key ones, and the last two are auxiliary ones; they are intertwined and affect each other (see Figure 1) [21–23]. However, opportunity factor is very complex and may appear in any period of industrial development, delivering uncertain (positive or negative) impact on competitiveness, so it is difficult to predict and measure it accurately in advance [8, 24–26]. In addition, over the past 10 years, the rapid development of the coal chemical industry in China has stemmed from the government's decision to launch a batch of clean coal utilization, coal-to-fuel, and coal deep-processing projects in China, as well as to build up a number of modern coal chemical enterprises at international advanced levels in Inner Mongolia, Shanxi, and Xinjiang rapidly by relying on the rich domestic coal resources [27–29]. Moreover, in order to better ensure energy security, the state has announced more than ten policies on the coal chemical industry, so as to support its development [30–32]. Therefore, this study would not select corresponding indicators to reflect the impact of opportunity factors on competitiveness, but modify the diamond model by using the government and other four factors jointly as key factors in analyzing the competitiveness of the modern coal chemical industry (see Figure 2).

3.2. Evaluation Index System for the Competitiveness of China's Coal Chemical Industry. By using the revised diamond model as the theoretical basis, this study adopts the analytic hierarchy process (AHP) to construct a competitiveness evaluation system for the coal chemical industry (see Table 1) [33–36]. This system includes three levels: (1) the first level, i.e., the target layer (A), which decides that the target is to evaluate the competitiveness of the coal chemical industry; (2) the second layer, i.e., the criterion layer (B), which establishes the evaluation criteria (B_1-B_5) for the coal chemical industry according to the five elements of the revised diamond model; and (3) the third layer, i.e., the index layer (C), which is further specific to the data and information that can be directly searched, surveyed, and calculated according to the content of the criterion layer, or to the indicators that have direct and important impact on the coal chemical industry. A total of 11 specific indexes (C_1 to C_{11}) are included.

4. Evaluation of the Competitiveness of Coal Chemical Industry

4.1. Data Processing. This study selects the original data from 2016 to 2020 for analysis. Given that the units of different index data are different, they must be standardized [37]. This study will use the normalization method to perform dimensionless processing on the original data in the following formula:

$$yi = \frac{xi}{\sum xi}, \quad (1)$$

where the new sequence $y_1, y_2 \cdots y_n \in [0, 1]$ is dimensionless, with $\sum y_i = 1$. And y_i refers to normalized data; x_i refers to original data.

The normalized data are shown in Table 2.

4.2. Index Weighting. On the basis of standardized data, this study adopts the entropy weight method to address the calculation of the weights of evaluation indexes. The concept of entropy comes from thermodynamics which is a measurement of the system state's uncertainty [38–40]. Shannon initially developed information theory for quantifying the information loss in transmitting a given message in a communication channel. [41–43] In information theory, entropy demonstrates the degree of disorder of information and can

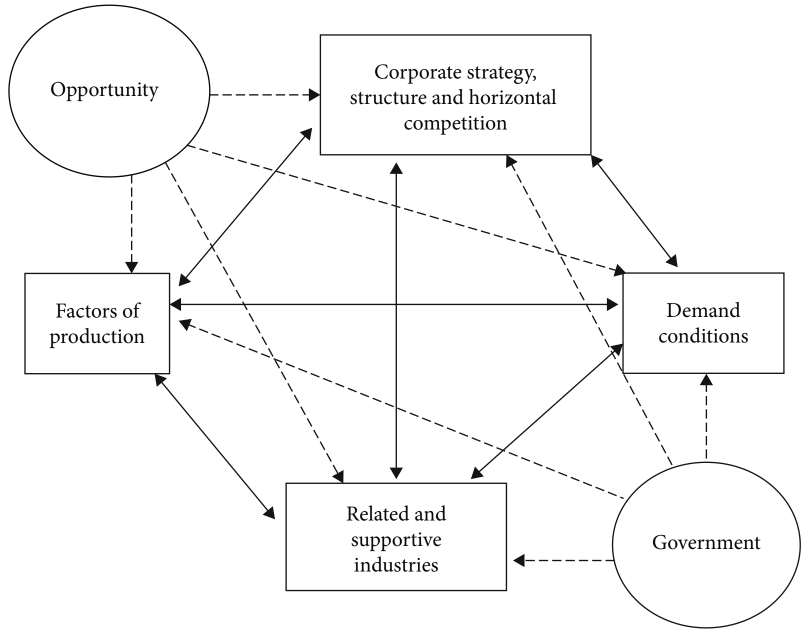

Figure 1: The diamond model.

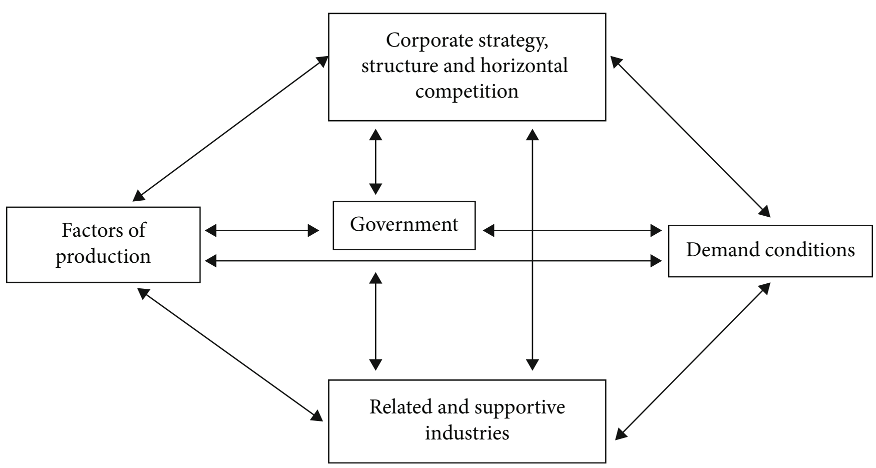

Figure 2: The revised diamond model.

be used to measure the amount of information. [44, 45] The entropy weight is used to decide the degree of dispersion of an index. The smaller the value of information entropy, the greater the degree of dispersion of the index, and the greater the influence (i.e., the weight) of the index on the comprehensive evaluation [46, 47]. This method can avoid the influence of human factors of each evaluation index as much as possible so that the evaluation results get more objective. The weighting results are shown in Table 3.

4.3. Evaluation of the Competitiveness of Coal Chemical Industry. The weights of the indexes under the same criterion layer are summed to obtain the weights of each criterion layer (see Table 4). Based on this calculation, the importance of the influence of each criterion layer on the competitiveness of the coal chemical industry is further ranked.

As shown in the calculation and ranking of the weights of all factors, the horizontal competition has the greatest impact on the competitiveness of the coal chemical industry, followed by production factors, related and supportive industries and the government, with demand conditions delivering the least impact on the competitiveness of this industry.

Based on the analyses above, it can be found that the horizontal competition in the coal chemical industry stems mainly from the impact of the oil and natural gas industry. This is because almost all of the modern coal chemical products can be produced with petroleum and natural gas, so they are highly interchangeable. In addition, compared with newly built large-scale refining-chemical integration projects, huge investment is required for modern coal chemical projects, and the investment per unit production capacity is 5 to 10 times that of refining-chemical integration projects. Moreover, modern coal chemical projects have high energy

Table 1: The evaluation index system for the competitiveness of coal chemical industry.

The target layer	The criterion layer	The index layer	Data source
Coal chemical industry's competitiveness A	Production factors B_1	Coal consumption of coal-to-oil or gas/(10,000 tons) C_1	*Energy Statistical Yearbook*
		Conversion efficiency of coal chemical industry/(%) C_2	*<Research on modern coal chemical technology, economy and industrial chain>*
	Demand conditions B_2	Annual consumption of coal chemical products/(10,000 tons) C_3	National Energy Group
	Related and supportive industries B_3	Annual gross output value of supportive industries/(100 million yuan) C_4	Network data statistics Note: The supportive industries mainly refer to the coal mining industry
		Total annual profit of supportive industries/(100 million yuan) C_5	
	Horizontal competition B_4	Crude oil imports/(10,000 tons) C_6	*Energy Statistical Yearbook*
		Natural gas imports/(100 million cubic meters) C_7	
		Self-production of crude oil/(10,000 tons) C_8	
		Self-production of natural gas/(100 million cubic meters) C_9	
	Government B_5	Annual gross product value of main producing areas of coal chemical products/(100 million yuan) C_{10}	National Bureau of Statistics
		Proportion of fiscal expenditure for coal chemical industry to the total fiscal expenditure/(%) C_{11}	

Table 2: Standardized data for competitiveness evaluation of coal chemical industry.

The target layer	The criterion layer	The index layer	2020	2019	2018	2017	2016
Coal chemical industry's competitiveness A	Production factors B_1	Coal consumption of coal-to-oil or gas/(10,000 tons) C_1	—	0.362	0.286	0.205	0.147
		Conversion efficiency of coal chemical industry/(%) C_2	—	0.249	0.249	0.250	0.252
	Demand conditions B_2	Annual consumption of coal chemical products/(10,000 tons) C_3	0.102	0.282	0.241	0.205	0.170
	Related and supportive industries B_3	Annual gross output value of supportive industries/(100 million yuan) C_4	0.216	0.268	—	0.275	0.241
		Total annual profit of supportive industries/(100 million yuan) C_5	0.185	0.236	0.241	0.247	0.091
	Horizontal competition B_4	Crude oil imports/(10,000 tons) C_6	—	0.286	0.261	0.237	0.216
		Natural gas imports/(100 million cubic meters) C_7	—	0.312	0.292	0.222	0.175
		Self-production of crude oil/(10,000 tons) C_8	0.202	0.198	0.196	0.198	0.207
		Self-production of natural gas/(100 million cubic meters) C_9	0.237	0.216	0.197	0.182	0.168
	Government B5	Annual gross product value of main producing areas of coal chemical products/(100 million yuan) C_{10}	0.227	0.223	0.206	0.182	0.162
		Proportion of fiscal expenditure for coal chemical industry to the total fiscal expenditure/(%) C_{11}	0.198	0.201	0.205	0.203	0.193

and water consumption, with heavy emissions of pollutants and carbon dioxide. Under the condition of low or medium oil prices, such projects have no cost advantage. Affected by the slump in international oil prices, modern coal chemical projects in China are basically operating below the break-even point; currently, as a result, many enterprises have to reduce or even stop production. However, at the political level, great powers achieve the goal of controlling the world politics by controlling energy, and this has become the basic logic of the energy politics in the world. The modern coal chemical industry can partially remedy the shortage of petrochemical products and ensure China's energy security. Therefore, to ensure the overall security and independence of China, it is necessary to develop the modern coal chemical industry and enhance its competitiveness.

Table 3: Weights of indexes.

The target layer	The criterion layer	The index layer	Weights
Coal chemical industry's competitiveness A	Production factors B_1	Coal consumption of coal-to-oil or gas/(10,000 tons) C_1	0.107
		Conversion efficiency of coal chemical industry/(%) C_2	0.101
	Demand conditions B_2	Annual consumption of coal chemical products/(10,000 tons) C_3	0.084
	Related and supportive industries B_3	Annual gross output value of supportive industries/(100 million yuan) C_4	0.102
		Total annual profit of supportive industries/(100 million yuan) C_5	0.084
	Horizontal competition B_4	Crude oil imports/(10,000 tons) C_6	0.102
		Natural gas imports/(100 million cubic meters) C_7	0.104
		Self-production of crude oil/(10,000 tons) C_8	0.079
		Self-production of natural gas/(100 million cubic meters) C_9	0.080
	Government B_5	Annual gross product value of main producing areas of coal chemical products/(100 million yuan) C_{10}	0.080
		Proportion of fiscal expenditure for coal chemical industry to the total fiscal expenditure/(%) C_{11}	0.079

Table 4: Weights of the criterion layer for evaluation of the competitiveness of coal chemical industry.

The target layer	The criterion layer	Weight	Ranking of importance
Coal chemical industry's competitiveness A	Production factors B_1	0.208	2
	Demand conditions B_2	0.084	5
	Related and supportive industries B_3	0.186	3
	Horizontal competition B_4	0.364	1
	Government B_5	0.159	4

5. Suggestions for Boosting the Competitiveness of China's Coal Chemical Industry

In conclusion, to enhance the competitiveness of China's coal chemical industry, suggestions should be made from the perspective of horizontal competition, which has the greatest impact on the competitiveness. Specifically, horizontal competition can be analyzed in two aspects: to avoid competition through differentiated development and to gain advantages in competition by boosting the conversion efficiency. These are where improvements can be made.

5.1. To Achieve Differentiated Development with the Oil and Gas Industry by Research and Development of New Products. At present, there is serious homogeneity between modern coal chemical products and oil/natural gas products.

To address this issue, the government can encourage and guide enterprises to focus on product differentiation and innovative development through relevant policies so that they can perform R&D of new technologies and products. According to the differences between coal-to-oil products and petrochemical products, the research and development of high-end oil products and chemical products shall be encouraged.

At the same time, coal chemical companies could extend their industrial chains, broad their product ranges, and develop new products based on the existing industry to get differentiated development. For example, in terms of extending the industrial chain, the comprehensive utilization of C4 resources can be strengthened in the field of coal-to-olefins through methanol, and high-end C3/C4 downstream derivative chemicals can be developed, such as nonanol, isononanol (INA), and polybutene. In terms of broadening the product ranges, while making diesel, high-temperature Fischer-Tropsch synthesis can be used to develop high-value-added fine chemicals and specialty chemicals that are difficult to obtain in the petrochemical industry, such as high-alpha olefins, super-hard waxes, high-carbon alcohols, rubber fillers, and lubricating base oils. In the field of development of new coal-based chemicals, efforts can be focused on the technical direction of synthesis gas to high-carbon primary alcohols.

5.2. To Improve the Transformation Efficiency of Coal Chemical Industry by Technological Innovation. By improving the efficiency through technological innovation, the coal chemical industry can become more advantageous in the competition against the oil and gas industry and related industries.

From the perspective of enterprises, firstly, coal chemical enterprises should establish the idea of advancing with the times, attaching importance to technological innovation in mindset. Secondly, coal chemical enterprises can enhance the transformation efficiency by raising the level of their technical equipment, establishing and improving multi-level scientific research institutions, and boosting the R&D

of the industry-critical technologies. Finally, coal chemical companies can continuously improve their management mechanisms, update the existing technologies, and optimize their resource allocation, so as to further improve the conversion efficiency.

From the perspective of the government, the state should formulate relevant policies to encourage the use of advanced technologies with high energy conversion efficiency and low pollution. For example, in terms of pressurized entrained bed gasification technology, China has already laid a good foundation, so support should be provided to further improve and engineer it.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no competing interests.

Authors' Contributions

Conceptualization, formal analysis, and writing-original draft preparation were made by Meihui Song. Formal analysis and writing-review and editing were made by Weicai Wang. Formal analysis was made by Shuoheng Sun. All authors have read and agreed to the published version of the manuscript.

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