Validation of Factors Influencing Green Supply Chain Development Based on Analytic Hierarchy Process and Game Theory

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Abstract. Emissions reduction and green energy application have become a global issue. Although many successful green initiatives are witnessed, it is difficult to identify the key factors influencing these successes and hence hard to replicate them. In this paper, we validate the factors influencing green supply chain development. First, we used the analysis hierarchical method (AHP) to do a qualitative and quantitative analysis of the interviews. Then, we employ game theory to build an n-firm Cournot-competition model for the firm development before and after green inputs. We conclude that investing in green manufacturing can result in a large increase in production and a higher profit for businesses. The results provide a solid theoretical basis for companies to facilitate their green supply chain development.

Keywords: Analytic hierarchy process · Cournot competition · Emissions reduction · Game theory · Green supply chain · Sustainability

1 General Instructions

The green supply chain is a hot topic in the manufacturing industry in recent years. The fundamental reason is that the current global environment is getting worse and worse, and along with the global temperature rise, heads of state are gradually shifting from rapid development of their industrial infrastructure to vigorous development of clean energy and green industries. Many countries are in the current domestic manufacturing enterprises to carry out green reform. The three pillars of the world economy, including China, the United States and the European Union, are the most obvious ones. Obviously, the world economic development and three industrial revolutions are accompanied by energy and technology revolutions, which can seize the new energy and sustainable development of the future energy change trend, will get a huge competitive advantage in the future. When economic development is not tied to traditional energy sources, but to renewable energy sources, a game will be formed between the speed of scientific and technological research and development, the level of machinery manufacturing and the quality of economic development. This study will discuss in detail the green supply chain development program in China and its implementation effectiveness outlook and

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influencing factors. This study targeted interviews with six top manufacturing companies in China. Through five different dimensions, such as current business situation, current dilemma, industry dilemma, policy inclination, and solutions, the problems, and solutions common to the seven enterprises are compiled, and an attempt is made to explore the significance level of the advancement of corporate Green Supply Chain Management (GSCM) development under multiple influences. With the help of AHP and game model to deduce the proof, it is concluded that among the multiple influences government support can have a significant impact on the manufacturing industry, green manufacturing has the highest importance for enterprises, and under the current stage, the market will gradually tend to autonomous green development.

The significant role of government moderating variables in the development of green and sustainable supply chains for manufacturing firms is inferred by using Analytic Hierarchy Process (AHP) as well as a game approach. The interviews provide a rationale for the paper to introduce influencing factors as multiple modifiable variables into our mathematical model in the context of a green sustainable global supply chain. In Sect. 3, the six top Chinese manufacturing companies interviewed and medium and large companies associated with green supply chains will be elaborated on. After analyzing the current development status of these six enterprises, the problems they encountered and their solutions, find out the commonalities in the industry, which leads to the fourth section: using AHP hierarchical analysis to deduce reasonable solutions, using game analysis to analyze the future development of the market, and providing a reasonable basis for enterprises to plan their green supply chain in the future. Then in the last section, summarize the conclusions deduced from this paper and extend to the whole green supply chain management (GSCM) field.

2 Literature Review

There are many variables and factors influencing the development of green supply chains, among which there are obvious adaptations and complementarities between variables and factors [8], while the simulation analysis of the obstacles encountered by manufacturing companies in the development of GSCM, developed based on explanatory structural modelling (ISM), can better provide a theoretical validation for the future implementation of Theoretical validation of GSCM can be made for future implementation [4]. The implementation of GSCM in the electrical and electronics industry has also led to a substantial investigation and development of the key factors of GSCM [2], and since the core objective of corporate development is its profitability index, the positive and significant effect of GSCM on corporate performance has become a driving force for innovative and green corporate development [9], GSCM implementation methods for polluting industries such as mining and research focus on the analysis of its drivers and sustainable development framework [6], while the development of GSCM is not only the responsibility of large enterprises, but also for GSCM is important not only for large enterprises but also for small and medium enterprises (SMEs), and the performance optimization of GSCM for sustainable development is significant for large enterprises as well as for SMEs [7]. Among them, the research on the moderating role of government policies on the implementation of GSCM and the impact of future decisions is in a blank stage.

In Sect. 3, the six well-known Chinese manufacturing enterprises interviewed and the well-known enterprises that have implemented GSCM will be elaborated in detail. In Sect. 4, the main derivation process and game model will be explained.

3 Interviews with Chinese Manufacturing Companies

Used in-depth interviews with executives of six Chinese manufacturing companies. The six Chinese companies ranging from traditional manufacturing to energy companies (Table 1).

Based on in-depth interviews of six Chinese manufacturing and energy companies, found that enterprises' demand for green growth and green manufacturing is more and more intense, enterprise from the passive development of green manufacturing, taking the initiative to put into research and development to the innovation in manufacturing, with the development of green supply chain, the enterprise green development objectives are to also clear. To explore the interrelationship of various factors that promote the green development of enterprises, including government policies, financial support, enterprise intentions, etc. (Table 2).

Based on the interviewees' accounts, we extracted six main influencing factors from them: number of patents, government support, earnings, regional economy, corporate honor (related to green development), and number of R&D personnel. For the interviewed companies, these factors are the first thing they should consider when making green development. Based on the actual development of the respondent companies, we have compiled 3 types of green development solutions that have been used in the respondent companies: green materials, green production, and disposal at the waste stage.

Table 1. Basic information of interviewees.

Enterprise	Gender	Age	Position	Educational Background
Quanlin Energy Ltd	female	48	manager	bachelor
Shandong Energy Group	female	36	manager	bachelor
PetroChina	female	53	Director of storage and transportation	master
China Ocean Shipping (Group) Company (COSCO)	male	55	department manager	associate
Freezer manufacturer located in Xinjiang	male	57	Strategy consultants	bachelor
Shanxi Coking Coal Group Co., Ltd.	male	Unknown	Workshop director	unknown

Table 2. Analysis of interview results.

Enterprise	Important content of the interview	The key point
Quanlin Energy Ltd	1. Factories can be built with 70% government subsidies, and patents can also bring profits 2. The more intellectual property there is, the more say a product has in the pricing of the market 3. Under the impact of COVID-19, the government has a tax rebate policy 4. Carbon neutrality has competitive advantages in the future	Government support is important Intellectual property can set prices The advantages of green manufacturing will emerge in the future
Shandong Energy Group	1. Green manufacturing is an emerging industrial trend with an achievable long-term sustainable future 2. Green supply chain involves multiple entities and links, and has high requirements on enterprise management ability and coordination ability 3. Enterprises will definitely have more green patents in the future 4. Protecting the environment is our responsibility. Green supply chain captures this demand 5. Enterprises that meet green standards can better establish an image of social responsibility	Patents are of high importance Green development is the only way for enterprises to go Green manufacturing can build a corporate image
PetroChina	1. As a key national enterprise, PetroChina has been attached of great importance by the government and solved many problems while keeping the epidemic prevention and control under control. 2. Only by transforming to green manufacturing can enterprises not be eliminated by The Times 3. Ensure the smooth production of the factory and the stable supply of raw materials to downstream customers.	The government gave a lot of help Ensure regional economy

(*continued*)

Table 2. (*continued*)

Enterprise	Important content of the interview	The key point
China Ocean Shipping (Group) Company (COSCO)	1. The state-directed appropriation is targeted at long-distance navigation enterprises. Without this appropriation, enterprises will be very difficult. 2. The number of patents is about 50 or 60, focusing on green shipping 3. Investment in green supply chain development reduces revenue to a certain extent, but green development is a long-term policy, which is positive and beneficial	The government propped up enterprise The patents focus on green development Research and development is positive and beneficial
Freezer manufacturer located in Xinjiang	1. Green investment should attract corresponding talents, and professionals should do professional things. 2. The Ministry of Environmental Protection provides subsidies through special funds. Without subsidies, it is difficult to make profits. 3. If enterprises do not invest in green development, they will be eliminated by the same industry in the future.	Government support, to a certain extent, to ensure the profitability of enterprises Research and development personnel are essential
Shanxi Coking Coal Group Co., Ltd.	1. Reasonable compensation should be given to enterprises that fulfil the obligation of protecting natural resources assets, which also arouses the enthusiasm of enterprises. 2. The enterprise accounts for 50% of the coal resources in China, so it has a considerable say. Therefore, it always attaches importance to the leading role of science and technology in green manufacturing and has 85 patent projects on the ring 3. Green manufacturing is the early investment, early return, is an important driver of enterprise scientific and technological innovation. 4. Technical transformation improves the overall economic benefits of enterprises.	Government subsidies mobilize the initiative of enterprises Regional economic development has a strong relationship with patent Green manufacturing inputs are important

4 Model Structures

Among many studies, the most difficult part is how to translate textual analysis into qualitative indicators, and many researchers have given different solutions. Reza Khorramshahgol and Raed Al-Husain (2021) [5] used AHP and Delphi in their study to construct goal programming, AHP is a multicriteria decision-making method with strong analytical power, and we believe that multicriteria decision analysis is more applicable for our current study. In Hu et al.'s (2014) [3] study, the Cournot model was used to analyses the optimal solution for the vegetable market in Taiwan, simulating the effects between the market, and the company We argue that this approach is also applicable to our study. We believe that the method is also applicable to the green supply chain strategy selection of companies. This study combines AHP, classifies the interview sample to derive the strategy, and analyses the market's yield change in the future by comparing the original situation with the profit of changing the green supply chain through the game model.

Based on the summary of the analysis of the interviews made, six influencing factors and three solutions were classified to achieve the GSCM goal, and an AHP hierarchical model was constructed based on the solutions.

Based on the interviews, the importance of each factor was scored by experts to determine the most important influencing factors for the implementation of a green supply chain, and pairwise comparison (PWC) matrices were constructed. This method may have a bias in the subjective scoring judgment, so we need to use the consistency test in the matrix, and according to the mathematical and statistical practice, the consistency of judgment is generally acceptable when the consistency ratio (CR) <= 10%, which is calculated as follows (Fig. 1).

Based on the two-by-two comparison of the six factors A = [A1, A2, A3, A4, A5, A6] in the criterion layer of the above figure, the weights ω were calculated by the square root method, whereupon the following table was obtained (Table 3).

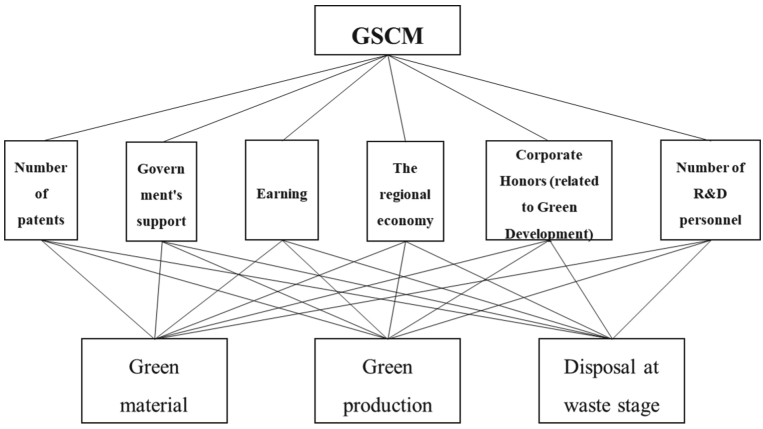

Fig. 1. Hierarchical model of GSCM development.

Table 3. Constructing pairwise comparison matrix.

	A1 Number of patents	A2 Government's support	A3 Earning	A4 Regional economy	A5 Corporate Honors (related to Green Development)	A6 Number of R&D personnel	weighted(ω)
A1 Number of patents	1	0.4444	0.8	4	2	0.6667	0.1481
A2 Government's support	2.25	1	1.8	9	4.5	1.5	0.3333
A3 Earning	1.25	0.5556	1	5	2.5	0.8333	0.1852
A4 Regional economy	0.25	0.1111	0.2	1	0.5	0.1667	0.037
A5 Corporate Honors (related to Green Development)	0.5	0.2222	0.4	2	1	0.3333	0.0741
A6 Number of R&D personnel	1.5	0.6667	1.2	6	3	1	0.2222

Calculation of CR values for consistency tests:

$$\boldsymbol{CR} = \frac{\frac{\sum_{i=1}^{n} \frac{[B\omega]_i}{n\omega_i} - n}{n-1}}{\boldsymbol{RI}} = \mathbf{0{<}10\%} \tag{1}$$

Consistency through, the table above to derive the individual weights of the six guidelines, according to the analysis of the results we can easily find that the majority of respondents believe that government support is very important, the interviewees have said that although the enterprise to implement green manufacturing, abandoned the past some high pollution production lines, the cost is higher, the enterprise pressure is also huge. Government subsidies can be used as an incentive for green development, and for enterprises, the subsidy is more important than just reducing costs, it is likely to be the key to turning a company into a profit. When talking about the green supply chain, the interviewees pointed out that enterprises want to develop green, but the lack of corresponding talent input in this area makes the implementation of the green supply chain more difficult. The lack of talent is one of the keys to supply chain transformation, and most companies believe that investment in R&D personnel is very necessary. One interviewee talked about profitability and cost, pointing out that pressure and motivation are dialectically unified, and the profitability situation can largely reduce the pressure and enhance the profitability as much as possible when the cost increases. Next, we need to calculate the weight scores of each factor in the criterion level for the scenario level

Table 4. Weight values of the three options.

	Green material	Green production	Disposal at the waste stage
ω	0.27529725	0.46146935	0.26314821

B = [B1, B2, B3] to better find the strategy, in the same way as above.

$$A_1 = \begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{2} \\ 2 & 1 & 1 \\ 2 & 1 & 1 \end{bmatrix} \tag{2}$$

$$A_2 = \begin{bmatrix} 1 & \frac{3}{5} & 2 \\ \frac{5}{2} & 1 & \frac{10}{3} \\ \frac{1}{2} & \frac{3}{10} & 1 \end{bmatrix} \tag{3}$$

$$A_3 = \begin{bmatrix} 1 & \frac{5}{4} & 2 \\ \frac{4}{5} & 1 & \frac{5}{2} \\ \frac{1}{2} & \frac{2}{5} & 1 \end{bmatrix} \tag{4}$$

$$A_4 = \begin{bmatrix} 1 & 1 & \frac{1}{2} \\ 1 & 1 & \frac{5}{6} \\ 2 & \frac{6}{5} & 1 \end{bmatrix} \tag{5}$$

$$A_5 = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \tag{6}$$

$$A_6 = \begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{2} \\ 2 & 1 & \frac{10}{7} \\ 2 & \frac{7}{10} & 1 \end{bmatrix} \tag{7}$$

The weights of B1, B2, B3 to A1 are [0.2, 0.4, 0.4]
The weights of B1, B2, B3 to A2 are [0.2662, 0.5814, 0.1524]
The weights of B1, B2, B3 to A3 are [0.4239, 0.3935, 0.1826]
The weights of B1, B2, B3 to A4 are [0.2582, 0.3062, 0.4356]
The weights of B1, B2, B3 to A5 are [0.3333, 0.3333, 0.3333]
The weights of B1, B2, B3 to A6 are [0.1989, 0.448, 0.3532]

From the above, we conclude that government support is the most important influencing factor in accomplishing the goals of GSCM, and through multi-criteria decision-making, we conclude that green production is the most important in accomplishing the goals. Most of the executives interviewed pointed out that the green supply chain is a combination of several complex processes and it is not possible to achieve green inputs quickly to be completely green, and companies are still under pressure from the impact of the epidemic and the cost of green inputs. Respondents believe that green manufacturing has evolved at this stage, and for respondent companies, replacing green materials is relatively simple and most improvements have been made in the midst of previous

planning. The remaining materials are not dealt with mainly for two reasons, (1) the part of the material is an important part of the product that is difficult to replace (2) the replacement cost of some materials is too high for the enterprise at this stage is somewhat difficult to afford (Table 4).

After we make our analysis at this point, we hope to see how the market might react in the future. The Cournot model is a simple duopoly model of output decisions proposed by Cournot in 1838. It has now become one of the most widely used models for analyzing the production behavior of each manufacturer in oligopolistic competitive markets. Most firms consider the green supply chain as the key to the future and the key to dominating the market, so we have derived the Cournot model and extended it to the production game of n firms in the market for analysis.

We assume that there are n firms playing in the market and that the firms will respond to the national policy and start to invest in green innovation. Based on our interview information, we conclude that most of the top managers believe that policy subsidies are the key for firms to continue their green supply chain, so we assume that government subsidies will have a greater impact on firms' profits.

(1) Original market production

The production cost of each enterprise is as follows, and is the production cost of the enterprise i

$$C_i(q_i) = cq_i \tag{8}$$

$\boldsymbol{c}$ is a non-negative real number, ($\boldsymbol{i}$ =1,2,3,…,n) is the output of firm $\boldsymbol{i}$, and the total output in the market is:

$$Q = \sum_{i=1}^{n} q_i \tag{9}$$

From the above equation, we can derive the profit function of the firm relatively simply, where $\boldsymbol{c} < \boldsymbol{a}$, $\boldsymbol{Q} < \boldsymbol{a}$.

$$\pi_i(q_1, q_2, q_3, ..., q_n) = q_i(p - c) = q_i(a - Q - c) \tag{10}$$

Next, the output mix of firm $\boldsymbol{i}$ in the Nash equilibrium is derived from the above equation and $\boldsymbol{q_k^*}$ represents the optimal choice of output by firms other than the firm.

$$\max_{0 \le q_i \le \infty} \pi_i(q_i, q_k^*) = \max_{0 \le q_i \le \infty} q_i\left[a - \left(q_i + q_k^*\right) - c\right] \tag{11}$$

$$q_i^* = \frac{a - c}{n + 1} \tag{12}$$

The Nash equilibrium is reached when each firm wants to become a monopolist in the market and will increase its output or price to dominate the market for maximum profit.

(2) Market output at the time of green input

The market starts to develop green manufacturing gradually, but the firms do not reduce their output and make themselves less competitive and thus exit the market as a result. To simplify the model structure and facilitate the study, we refer to Guan et al.'s (2020) [1] study, the green innovation input and cost relationship are $\frac{1}{2}he^2$, h is the cost parameter, e is the green innovation input, and the optimal output is calculated as in (1). Based on the interviews, it appears that government subsidies are related to the effects after the final output. There are many companies that do not have much effective output after making a lot of green inputs, and the government is not going to give subsidies to correspond to too many inputs. Therefore, we have adopted $\beta\mu$ to represent government subsidies to companies, and the remaining parameters are: β is the government subsidy and μ is the influence coefficient of the market price.

$$p = a - Q + \mu e \tag{13}$$

$$\max_{0 \le q_j \le \infty} \pi_j = \max_{0 \le q_j \le \infty} q_j\left(a - q_j - q_k^* + \mu e - c\right) - \frac{1}{2}he^2 + \beta\mu \tag{14}$$

$$q_j^* = \frac{a - c + e\mu}{n + 1} \tag{15}$$

We can clearly see that after the implementation of the green supply chain $q_i^* \le q_j^*$. When the market reaches equilibrium, there is a significant increase in production and the market will no longer depend on government subsidies and production will be determined by demand and green inputs. Respondents believe that green production is the key to the future and that an appropriate increase in costs is necessary in order not to exit the market. With government subsidies, it is possible to reduce costs to a certain extent and reduce the pressure on companies, which confirms the respondents' belief that green inputs are necessary (Fig. 2).

The graph shows two profit function graphs of the original situation and the situation after the green input is started. We can clearly see from the graph that the function of green input has a higher slope and a faster growth rate. When weighing the costs and future benefits of a green supply chain, $\beta\mu - \frac{1}{2}he^2 \ge 0$. That is, they can obtain higher returns than they otherwise would. However, from a practical point of view, the government cannot give subsidies to enterprises that have no output, so the output of enterprises needs to $q_i \ge \frac{he}{2\mu} - \frac{\beta}{e}$ Only then can get higher profits. At the same time, we believe that production in $(0, \frac{\frac{1}{2}he^2 - \beta\mu}{a - q_j - q_k^* + \mu e - c})$ Such an unprofitable region can use green products to eliminate several enterprises that cannot be transformed. Therefore, we believe that green investment is what manufacturers must do in order not to withdraw from the market.

For enterprises, green investment may be less profitable in a small range, but in the long run, the benefits outweigh the disadvantages.

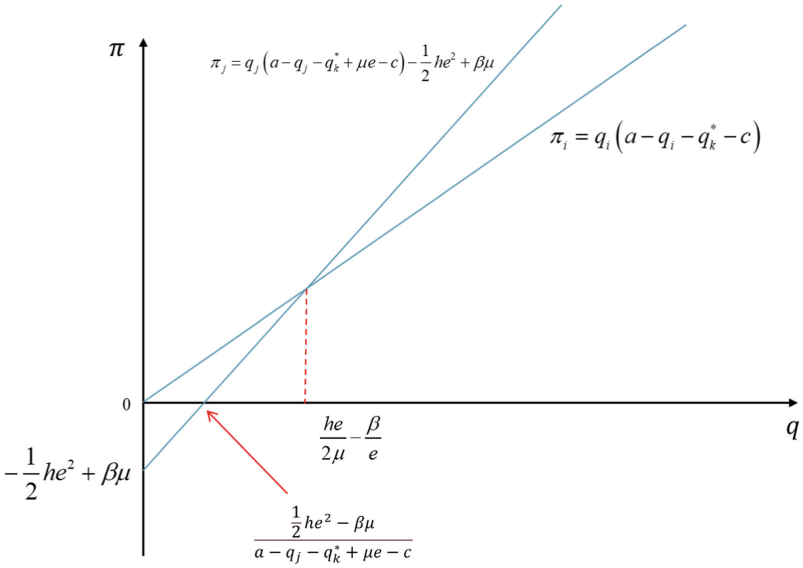

Fig. 2. Profit function for 2 cases.

5 Conclusion

In the context of China's efforts to develop green manufacturing, we conducted in-depth interviews with senior executives of seven Chinese manufacturing enterprises, most of which are state-owned energy enterprises. We used AHP to successfully find the green supply chain improvement scheme with the highest weight: green manufacturing, which is consistent with the statement provided to us by the interviewees. At the same time, to better understand the possible development and changes in the future, the Cournot model game was introduced to compare the changes in the output of enterprises after green manufacturing, and we were surprised to find that the product output of enterprises had a high increase meanwhile, from the market level, enterprises began to spontaneously carry out green manufacturing. In summary, for enterprises that have implemented GSCM development, the government's sustainable policy adjustment has a significant positive effect on the development of GSCM. At the same time, it is not difficult to see from our interview that the policy implementation degree of state-owned enterprises is much better than that of private enterprises.

The sample size in the article was small, thus, there may be some discrepancies with reality. Due to a few selected effects, the first model is limited in complexity and may contain unconsidered aspects, and more correlations between variables will be considered in future studies. Second, the sample size is small, and there are several constraints that may be addressed by expanding the target group for the interviews or supplementing additional questionnaires. Third, the work only looked at changes in yield variation; other relevant factors may also have a role, and more research is needed.

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