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Research Article

Evolutionary Game of Value Synergy in Industrial Chain: In the Context of "Chain Chief System"

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The "chain chief system" is an institutional innovation that can enhance the responsibility of the industrial chain. Currently, various provinces and cities in China are adopting it to reap the benefits of resource combination. Traditional industrial synergy emphasizes "scale orientation," and research on industrial policy, involving government administrative power, needs to be thoroughly discussed from the perspectives of government behavior and industry characteristics. This study utilizes the evolutionary game method to analyze the behavioral strategies of the government, leading enterprises, and other enterprises in the industrial chain under different conditions based on the perspective of value synergy. Relevant parameters of revenue and cost are modified for numerical simulation. The results demonstrate that the evolutionary stability strategy is influenced by various factors such as the government's due diligence, subsidies, proportions allocated to different enterprises, benefits and costs, and industrial characteristics. Furthermore, the government can appropriately increase subsidies to leading enterprises and penalties for inaction, reduce barriers to data and scene sharing among enterprises in the industry, and lower industry concentration. These measures are more conducive to establish a "chain chief system" value synergy ecology in which all members actively participate.

1. Introduction

The "chain chief system" is an innovative system designed to enhance accountability within industrial chains. Under this system, the local government designates the relevant official as the "chain chief" of the industrial chain, who assumes the role of industry builder and coordinator. The "chain chief" takes charge of the upstream and downstream sectors of the chain, promotes the industrial cycle, market cycle, economic and social cycle, and fosters the formation of the industrial chain ecology [1]. The "chain leader enterprise," on the other hand, is the core enterprise in the industrial chain that coordinates the activities of all nodes in the chain, ensuring that the entire industrial chain functions as an organic whole. This "chain chief system" was first introduced in Changsha, Hunan Province, and later widely promoted by Zhejiang Province. Today, cities across China are gradually adopting this system to facilitate the integration and synergistic development of industrial chains with local characteristics.

The "chain chief system" constitutes a macrolevel industrial chain policy, characterized by a distinct theoretical foundation and focal point, as compared to the traditional industrial chain policy. The latter, grounded in the notion of "market failure" [2], aims to attain economies of scale, regulate industrial access via development zones, identify key industries (such as traditional, pillar, and emerging industries), construct significant industrial zones (e.g., economic and technological development zones, export processing zones, and high-tech industrial development zones), and foster diverse implementation policies, among other factors. These endeavors have a palpable impact on both productivity and the optimization of the industrial structure [3]. Conversely, the "chain chief system" subscribes to the theoretical basis of "market division of labor," wherein the government or prominent enterprises shoulder specific links and responsibilities across the chain [4]. This distinctive policy orientation similarly exerts a pronounced impact on productivity and industrial structure optimization. The "chain chief system" is also an industrial chain responsibility system with administrative forces involved [5]. Previously, discussion of the chain responsibility system was primarily concerned with the industrial division of labor from a globalization perspective. Scholars have scrutinized the implementation and ramifications of the EU's chain responsibility policy in particular [6]. Research on the industrial chain responsibility system from the lens of globalization has progressed from exploring responsibility among governments to investigate the game among multinational corporations. Due to the fragmentation of property rights, production, and the network of transactions and operations, the geographic scope of multinational companies' activities no longer adheres to national boundaries, but rather to specialized division-of-labor structures, thereby engendering a novel governance mechanism. In contrast to the EU, China's chain responsibility system does not prioritize issues such as labor rights and environmental governance among economies but rather emphasizes the government and leading enterprises' "normative power" to guide the synergy of industrial and innovation chains [7]. This aligns with the trend among scholars who advocate for a shift from private governance to "back to government" and "back to coercion" in the area of industrial chain responsibility [8, 9]. Nonetheless, these qualitative studies fail to address how the government can optimize the effect of industrial synergy by adjusting the means of industrial chain implementation in multi-participant scenarios.

"Chain chief system" is also a kind of synergy of value creation and value capture. In this system, overseen by the government, the industrial chain, innovation chain, capital chain, talent chain, and data chain are interconnected, focusing on both the demand and supply sides of transactional value. This amplifies the economic value of the enterprise's activities through a synergy of value creation that emphasizes the interests of multiple parties. This model of value creation involves stakeholders cooperating to meet the value needs of individual value creators [10]. Corporate subjects realize this value creation through the dynamic process of perceiving potential synergistic values, agreeing on transactions, and playing both sides [11]. Under the "chain chief system," value synergy is based on the sharing of resources, which can bring about three effects: complementary, synergistic, and cluster effects [12]. These effects lead to greater efficiency in the use of physical and financial assets and increased effectiveness of intangible resources in separate markets. New industries, particularly in the digital economy, must foster industrial development through the chain chief system, which allows the merging of existing combination of resources to yield portfolio benefits.

In the realm of multisubject industrial chain governance and synergy with government intervention, the topics of innovation and R&D synergy have garnered most attention. Of these, game theory has proven to be an effective tool for investigating industrial chain synergy [13–15], while evolutionary models are commonly employed to examine decision-making and optimization solutions. Indeed, prior studies have demonstrated that policy instruments such as strategic support [16], tax incentives [17], regulation, and penalties [18, 19] can bolster interfirm relationships and stimulate chain cooperation. These works, however, tend to offer granular solutions tailored to specific industries (e.g., hotel [20] and logistics [21]) and thus leave much to be desired in terms of comprehensiveness.

(1) In China's unique environment, the "chain chief system" has emerged as a policy tool. The academic research on this topic, predominantly within China, has focused on providing case studies and theoretical underpinnings for the system's implementation in specific industries [4, 5]. However, there is a lack of abstract and quantitative theoretical discussion, and no research has explored the "chain chief system" from the perspective of game theory and value synergy theory. (2) The existing literature on this topic is largely concerned with the specific coordination of particular industrial chains. The "chain chief system," on the other hand, is a macrolevel industrial chain system design that transfers the responsibilities of the industrial chain to the government and leading enterprises. Despite the system's importance, no literature has yet applied game theory to study the value synergy mechanism of the "chain chief system." (3) Differentiation of enterprises by the "chain chief system" gives rise to a unique set of incentives for the government. In contrast to direct subsidies for cooperative innovation, which have been studied in existing game theory research [14, 22], the "chain chief system" requires subsidies for different subjects at varying intensities, and their effects need further exploration.

Given the research gap, the rest of this study will be allocated as follows: Section 2 is the interpretation of related concepts and literature review, Section 3 is the construction process of the "chain chief system" model of value synergy, Section 4 is the solution of the model, and Section 5 is the numerical simulation and analysis of the model. Section 6 is the analysis and conclusion of the simulation results.

2. Literature Review

2.1. Value Synergy of Industrial Chain under "Chain Chief System". The concept of the industrial chain not only covers the industrial organization relationship of similar enterprises as pointed out by the concept of industry but also includes the economic transaction links between enterprises upstream and downstream of the industrial chain [20]. Compared to the value chain and supply chain, the industrial chain offers a more expansive perspective, which can be broken down into four components. First, it reflects the amalgamation of multiple industrial levels that are made up of distinct production and operation systems within a particular industry or market. Second, it reflects the extent of interdependence between industries, encompassing the close associations and synergistic relationships between multiple industries or supply chains. This includes the vertical relationship between upstream and downstream as well as the horizontal relationship between similar divisions of labor and mutual complementarity [23]. Third, the industrial chain system takes into account the time dimension of various links in economic operations and the spatial distribution of each link within a region. Fourth, the industrial chain also reveals the degree of integration of social resources and the extensive collection of resources and capabilities in the entire socioeconomic sphere to create industrial competitiveness [24]. The macrolevel management norms and institutional systems that govern the industrial chain serve as the governance mechanism in the process of realizing value creation, and these systems influence the formation of the value distribution mechanism in the industrial chain [25].

Value synergy is a process that enhances the efficiency of resource allocation and generates more value [26]. The "chain chief system" is a governance mechanism for industrial chains, which receives government endorsement and facilitates resource sharing and value cocreation among all participants [27]. By allocating and transferring authority and responsibility for industrial chain governance, the system establishes a division of roles in value production, transmission, and acquisition. Central enterprises with strong capital, equipment, and capacity can guide other enterprises in the chain to carry out necessary research and development and promote the diffusion of industrial common technologies. Therefore, they are often chosen as chain leader enterprises to lead and respond to national economic and scientific strategies. The interrelated production and operation units within the socioeconomic scope ultimately achieve a common value proposition by integrating resources, achieving overall value-added and structural optimization of multiple industries.

2.2. The Role and Benefits of Government in Industrial Chain Value Synergy. The industrial chain represents a mix of competition and cooperation between various entities involved in the inputs and outputs of the system. The goal of the chain chief is not merely to maximize the value of the enterprise but to improve the overall capacity of the chain [4]. As the chain chief, the government is responsible for providing incentives, coordination, and public goods for the chain and planning and allocating public resources through industrial policies. This involves addressing the problem of incentive failure within the industrial chain through taxation, special subsidies, and the establishment of industrial funds [28]. The government can also leverage public data resources to build an industrial data platform and create a digital industrial chain. The industrial chain is an industrial ecology created by the "invisible hand" of the market, and the relationship between the chain leaders, i.e., the core enterprises, is a supply chain cooperation network formed through dynamic market competition. However, the government can easily overstep its bounds and interfere with market development by assuming the role of the main business entity, especially when political achievements are at stake. At times, the government may provide undue advantages to certain enterprises within the chain or overextend its power in an attempt to maintain the integrity of the industrial chain [29]. It is imperative for the government to clearly define the boundaries of its power under the "chain chief system," to prevent the unlimited expansion of its role, and to avoid the trap of an "all-powerful government." The government must consider the appropriate degree of administrative power to use while implementing this system.

To fulfill its fundamental revenue-raising function, the government relies on taxes, which are collected based on the tax base that best reflects the creation of social value [30]. Through the design of various corporate tax systems, the distortions in resource allocation in the industrial chain can be minimized [31, 32], and the tax system can continuously optimize spatial resource allocation and enhance the performance of industrial upgrading as production becomes more specialized. In addition, the design of a local tax system that aligns with the development of urban clusters can significantly boost industrial upgrading and combat local protectionism and duplication of construction behaviors [33], thereby improving the efficiency of the spatial division of labor [34, 35]. While previous research treats taxes primarily as a source of government revenue [36, 37], this study regards taxation as a crucial way for the government to play a key role in supply chains and industrial chains. As such, this study will explore the government's function in industrial chains through the lens of taxation.

2.3. Impact of Industrial Characteristics on Value Synergy of the Industrial Chain. Industrial evolution is a complex phenomenon shaped by various factors, including technological knowledge, market demand, industry supply, and institutional environment [38]. The dynamic interplay of these driving forces creates industrial characteristics, which are manifested in the cyclical evolution of industries concerning the number and bargaining power of firms, and the direction of innovation. Economists commonly use metrics such as the number of firms, gross product value, and market concentration to describe industries [39, 40], with the latter being the most significant factor in determining market behavior and performance [41]. Existing research has shown that market concentration and innovation exhibit a variety of relationships, ranging from "*U*-shaped" to "inverted *U*-shaped," "*M*-shaped," and "*V*-shaped" [42–45]. In addition, technology demand conditions are critical factors affecting innovation and output performance indicators in industries such as China's high-tech manufacturing industry [46]. Although moderate industry concentration benefits technological innovation and R&D performance, overconcentration hinders R&D efficiency [47]. Finally, optimal fiscal subsidy policies differ according to market structures, including perfect competition, oligopoly, and monopoly, and their effects on social welfare also vary accordingly.

In the realm of game theory applied to financial subsidy strategy with government regulation, industrial characteristics are crucial for synergy. The level of industrial innovation, for instance, impacts the capacity of leading enterprises to innovate [48]. Legal regulation of intellectual property rights also affects knowledge sharing [49]. Market size and technology diffusion difficulty are other critical variables that are often included in the model [50, 51]. Some scholars have approached the study of, low-carbon industry [52], industrial parks [53], and platform economies [54] from an evolutionary game perspective. They have investigated the upstream and downstream cooperation patterns, industrial policies, and the resulting synergistic effects of industrial chains. The benefits of cooperation can be subject to risks since initial industrial inputs and benefits are interdependent. The degree of risk is associated with the industry in which they operate, as indicated by market concentration. In industries with high homogeneity, short industry chains, and significant barriers to data and scenario sharing, the cost and difficulty of cooperation are relatively high, such as in the textile industry. Conversely, industries with low homogeneity, long industry chains, and low barriers to data and scenario sharing have lower costs and difficulties of cooperation. The intelligent network connection and new energy automobile industry, for instance, are prime examples of industries that have low homogeneity, long industrial chains, and low barriers to data and scene sharing, which allows for the formation of a rich industrial ecology comprising upstream, midstream, and downstream based on the industrial park.

2.4. Organizational Trust and Free-Rider Behavior. In *The Logic of Collective Action*, Olson put forth the concept of "free riding," which suggests that if members of a group fail to act collectively and rationally, they will not be able to achieve their collective goals if they all reap the benefits. The underlying cause of this behavior is a crisis of trust within the industrial chain. The supplier-buyer strategic relationship is widely recognized as an effective approach for coping with the volatile business environment [55]. Trust among supply chain companies plays a critical role in achieving supply chain cooperation. Unlike economic contracts, trust is used as a relational contract to coordinate relationships among supply chain member firms, and it is a type of relational capital that helps reduce opportunism, transaction costs, and uncertainty [56]. Trust among chain members implies that one member trusts the other and is willing to fulfill its commitment based on the premise of risk and interdependence. In studies related to industrial chains and supply chains, trust is further categorized. For example, Celuch et al. [57] identify two types of trust: individual-based trust and institution-based trust. Ganesan [58] divides trust in supply-purchase relationships into two categories: reliability trust and goodwill. Taking the Chinese context into account, Yang [59] also classifies trust into computational trust and relational trust. These trust classifications highlight three dimensions of trust: first, the behavior of cooperating firms in fulfilling their commitments from a competence perspective; second, the use of contracts to regulate the willingness of cooperating firms to fulfill their commitments from a contractual perspective; and third the behavior of cooperating firms in committing to win-win situations and rejecting opportunism from a goodwill perspective [60]. Free riding, a short-sighted and opportunistic behavior caused by a lack of goodwill and trust among upstream and downstream enterprises in the industrial chain, is not conducive to industrial chain value synergy.

In the context of major technological breakthroughs in strategic emerging industries, complementary advantages between enterprises lead to the generation of value-added technology through the transformation of existing technology or original innovation, resulting in mutually beneficial synergies. However, in practice, upstream enterprises utilize advanced information technology such as web crawlers and big data mining to process information flow generated by collaborative innovation, discern the dynamics of existing and potential competitors, and accurately define market demand. Although technology spillover to the outside environment is temporarily suppressed to some extent by confidentiality agreements between enterprises, the risk of imitation or technology leakage due to malicious competition or unethical behavior cannot be ruled out. Scholars studying the game behavior of enterprises in supply chain investment [61], marketing pricing [62], and service decision-making [63] consider free-riding behavior as an important variable that affects game outcomes. In the "chain chief system" value synergy of the industrial chain, free-riding behavior is also included as a crucial factor.

3. Construction of "Chain Chief System" Value Synergy Model

3.1. Model Assumptions. According to the literature review and the actual situation, this study makes four basic assumptions.

Assumption 1. In the context of the "chain chief system," achieving synergy requires the interaction and cooperation of three main entities: the government, the chain leader enterprises, and other enterprises within the chain. These actors engage in decision-making processes that influence one another and ultimately converge to an evolutionary equilibrium.

Assumption 2. The decision-making process in the "chain chief system" involves three players—the government, the chain leader enterprises, and other enterprises in the chain. Each actor has finite rationality and can choose only two strategies. The government's strategies are to either assume its chain chief's duties or not, while the chain leader enterprises can either take on their responsibility or shirk it. Similarly, other enterprises in the chain have the option to cooperate with the chain leader enterprises or not, i.e., the government (fulfillment and nonfulfillment), the chain leader enterprises (assumption and nonassumption), and other enterprises (cooperation and noncooperation).

Assumption 3. Due to information asymmetry, free riding is allowed in the process of value synergy in the industrial chain [54].

Assumption 4. The outlay required to set up an industrial chain value synergy mechanism varies across different industries, and the allotment of gains between the chain chief enterprises and other enterprises also shows variation between industries.

3.2. Variable Description. Informed by the work of He et al. [64] and Yang and Liu [65] and the concept of incrementality, this study splits the costs borne by the government while implementing the chain chief system into two categories: the basic cost and the due diligence cost. The latter includes investments by the government, such as the creation of public industrial funds and the establishment of public service and data platforms, as well as targeted subsidies for different enterprises. The government can calibrate each support cost while facilitating value synergy in the industry chain. Similarly, the government's benefits when implementing the chain chief system can be divided into three parts: the basic benefits when the government abstains from its duty, the incremental basic benefits when it does its duty, and the potential benefits of industryial chain value synergy. By performing the role of the chain chief, the government fosters a stable environment that facilitates regional investment cooperation and consistent enterprise production. In addition, due to the government's resource coordination, the potential benefits of industrial chain value synergy when it performs its duty will be more significant than when it does not.

3.2.1. The Enterprise Benefit-Cost Variable. The benefits derived from combining resources are greater than those obtained by utilizing individual resources in isolation by the hypothesis of value synergy [27]. In the context of the "chain chief system," the government assumes responsibility for overseeing the chain to help foster synergy. Due to institutional pressures, companies are likely to exert influence on the policy landscape of their environment [66]. To support key industrial chains, the government provides development platforms and various forms of assistance such as building industrial blocks or key parks, offering strategic consulting services and comprehensive public service platforms for industrial chains, and establishing information and data sharing mechanisms. These initiatives serve to enhance the efficiency of enterprise cooperation and increase the benefits of collaboration.

3.2.2. Enterprises That Engage in Cooperation Face Search, Trust, and Coconstruction Costs. These costs are affected by two factors: whether the government dominates industrial chain coordination and whether enterprises cooperate. These costs are considered preexisting costs [67, 68], which must be incurred before the cooperation can take place. For the chain owner enterprise, the cost includes creating special teams to cultivate relationships with the chain leader and other enterprises in the industrial chain, developing supplier-related standards, and leading the way in digitalization to enable efficient operations and cooperation within the industrial chain. For example, Guangzhou Automobile Group is the chain owner enterprise for Guangzhou Intelligent Network and the new energy automobile industry. AION, a subsidiary of Guangzhou Automobile Group, has established an autonomous driving technology research and development team and cooperated with upstream and downstream enterprises, such as Contemporary Amperex Technology Co., Limited, in constructing a battery factory in the smart factory industrial park. This partnership facilitated advancements in new energy vehicles, intelligent driving, and new materials within the park. Other enterprises incur costs related to production and data interface planning, which conform to the standards set by the chain leaders [69, 70]. When the government assumes the role of chain chief, it not only reduces the search cost of enterprises seeking cooperation partners but also endorses cooperation among enterprises in the industrial chain, thereby reducing trust costs associated with selecting cooperation partners. In addition, the government can reduce coconstruction costs by building industrial parks, platforms, and other cooperative infrastructure. When the government takes on the responsibility of chain chief, the cost of cooperation is lower and the benefits generated by industrial chain value synergy are greater than when enterprises are responsible.

3.2.3. Industrial Characteristic Variables. This study extends the existing literature to use industrial concentration as an indicator of industrial differences [71, 72]. When the industry has high enterprise homogeneity, a short industry chain, and large barriers to data and scene sharing, the difficulty and cost of cooperation between enterprises will be relatively large, such as the textile industry; conversely, when the industry has low enterprise homogeneity, long industry chain, and low barriers to data and scene sharing, the difficulty and cost of cooperation between enterprises will be relatively small. On the contrary, when the enterprises in the industry have low homogeneity, long industrial chain, and low data and scene sharing barriers, the difficulty and cost of cooperation between enterprises will be relatively small, and it is easy to form a rich industrial ecology including upstream, midstream, and downstream based on the industrial park, such as the intelligent network connection and new energy automobile industry.

3.2.4. Free-Riding Behavior Variable. According to the hypothesis of value synergy, sharing-based collaborative value creation cannot avoid "free riding" [73]. Referring to the study of Bernstein [63] and He et al. [64], the free-riding benefit variable is introduced in this study. When only one of the chain leader enterprises and the other firms adopt the positive cooperation strategy under the chain chief system, the one who adopts the negative strategy generates free-rider benefits. Since the government will regulate the market to avoid free-rider behavior, the free-rider gain when the government does its chain chief duty industrial chain support is smaller than the free-rider gain when the government does not perform its duty.

In summary, this study selects the relevant cost and benefit variables, as shown in Table 1, and constructs a tripartite mixed strategy game matrix among the government, chain leader enterprises, and other enterprises.

According to the basic assumptions, the benefits' matrix containing the behaviors of government, chain leader enterprises, and other enterprises is constructed, as shown in Table 2.

4. Model Solving and Analysis

4.1. Solving the Revenue Function. Based on the payment matrix of the tripartite game in Table 2, when the government selects the "fulfillment" strategy, its expected return can be expressed as E_{g1} and E_{g2} can be used to describe its expected return of the "nonfulfillment" strategy:

$$\begin{aligned}E_{g1} &= yz\left(U_1 + U_1' + \Delta U_1 - G - G_0 - G_e - G_s\right) + y(1-z)\left(U_1 + U_1' - G - G_0 - G_e\right) + (1-y)z\left(U_1 + U_1' - G - G_0 - G_s\right)\\ &\quad + (1-y)(1-z)\left(U_1 + U_1' - G - G_0\right)\\ &= U_1 + U_1' + yz\Delta U_1 - G - G_0 - yG_e - zG_s, E_{g2} = U_1 + yz\Delta U_1' - G_0.\end{aligned} \tag{1}$$

Similarly, when the chain leader enterprises select the "assumption" and "nonassumption" strategies, respectively, the expected return can be expressed as E_{e1} and E_{e2}:

$$\begin{aligned}E_{e1} &= xz\left(U_2 + G_e + \alpha kD - C_e - \beta\Delta C_e\right) + x(1-z)\left(U_2 + G_e - C_e - \beta\Delta C_e\right) + (1-x)z\left(U_2 + \alpha kD' - C_e - \Delta C_e\right)\\ &\quad + (1-x)(1-z)\left(U_2 - C_e - \Delta C_e\right),\\ E_{e2} &= xz\left(U_2 - g - C_e + N_1\right) + x(1-z)\left(U_2 - g - C_e\right) + (1-x)z\left(U_2 - C_e + N_1'\right) + (1-x)(1-z)\left(U_2 - C_e\right).\end{aligned} \tag{2}$$

When the other enterprises in the industrial chain select the "cooperation" and "noncooperation" strategies, respectively, the expected return can be expressed as E_{s1} and E_{s2}:

$$\begin{aligned}E_{s1} &= xy\left(U_3 + (1-\alpha)kD + G_s - C_s - \gamma\Delta C_s\right) + x(1-y)\left(U_3 + G_s - C_s - \gamma\Delta C_s\right) + (1-x)y\left(U_3 + (1-\alpha)kD' - C_s - \Delta C_s\right)\\ &\quad + (1-x)(1-y)\left(U_3 - C_s - \Delta C_s\right),\\ E_{s2} &= xy\left(U_3 - C_s + N_2\right) + x(1-y)\left(U_3 - C_s\right) + (1-x)y\left(U_3 - C_s + N_2'\right) + (1-x)(1-y)\left(U_3 - C_s\right)\\ &= U_3 - C_s + xyN_2 + (1-x)yN_2'.\end{aligned} \tag{3}$$

Table 1: Model parameters.

	Variables	Specific content
Government (chain chief)	U_1	The basic benefit is when the "chain chief system" is in place but the government fails to perform its duties
	$U_1{}'$	Incremental base earnings when the government performs its chain chief duties
	ΔU_1	The government's revenue is when the government takes full responsibility as the chain chief and establishes the corresponding industrial chain value synergy ecology
	$\Delta U_1{}'$	The government's revenue when the government fails to fulfill the responsibility of chain chief, and the enterprises in the industrial chain spontaneously form the industrial chain value synergy ecology
	G_0	Basic input from the government when implementing the "chain chief system"
	G	The government's public investment in the industrial chain when doing its duty of chain chief, such as formulating "one policy for one chain," building industrial blocks or key parks, providing industrial chain strategic consulting institutions and comprehensive public service platforms, and establishing information and data sharing mechanisms
	G_e	Government incentives and subsidies for chain leader enterprises
	G_s	Government incentives and subsidies for other enterprises in the industrial chain
	x	The probability of the government fulfills its duty as chain chief
	$1-x$	The probability that the government does not fulfill its duty as chain chief
Chain leader enterprise	U_2	The basic revenue of the chain leader enterprises under the "chain chief system"
	C_e	The basic cost of the chain leader enterprises when their responsibilities are not assumed
	ΔC_e	The cooperation cost for the responsibilities of the chain leader, such as developing supplier standards, building upstream and downstream cooperation systems, and setting up specialized departments to connect with cooperators
	g	Penalties in case of noncooperation or inaction of the chain leader enterprise
	N_1	In the case where the government assumes the responsibility of the chain chief, the free-riding benefits of the chain leader enterprise when the chain leader enterprise does not assume the responsibility of the chain leader and other enterprises actively cooperate
	N_1'	In the case that the government does not assume the responsibility of the chain chief, the free-riding benefits of the chain leader enterprise when the chain leader enterprise does not assume the responsibility of the chain leader enterprises and other enterprises actively cooperate
	y	Probability of the chain leader enterprise assuming chain-owning responsibilities
	$1-y$	Probability that the chain leader enterprise does not assume the responsibilities of the chain leader

Table 1: Continued.

	Variables	Specific content
Other enterprises in the industry chain	U_3	The basic revenue of other enterprises in the chain chief system
	C_s	The basic cost of other enterprises in the chain chief system
	ΔC_s	Additional cooperation costs for other enterprises to cooperate with the chain leader enterprises, such as carrying out production according to the standards of the chain leader enterprises
	N_2	The free-riding benefits of the other enterprises in the case where the government and chain leader enterprises are doing their duties
	N_2'	The free-riding benefits of the other enterprises in the case where the government and chain leader enterprises are not doing their duties
	z	The probability of other enterprises cooperating with the industrial chain value synergy
	$1 - z$	The probability that other enterprises will not cooperate with the industrial chain value synergy
Synergistic benefits and cost of cooperation variables	D	The overall incremental net benefit to the business results from industrial chain value synergy when the government performs its duty as chain chief
	D'	The overall incremental net benefit to the business results from industrial chain value synergy when the government does not perform its duty as chain chief
	k	The revenue coefficient, which acts on revenue D, takes into account the industrial characteristics, risks, and return on the initial investment. A larger k indicates a greater contribution to the revenue
	α	The distribution coefficient of the industrial chain synergy income, the distribution coefficient of the chain leader enterprise is α, then the distribution coefficient of other enterprises is $1 - \alpha$. When α is close to 1, it means that the concentration of the industry is high
	β	Cost coefficient, which acts on the extra cost paid by chain leader enterprises for industrial chain value synergy, when there are fewer barriers to industrial data or scene sharing, there is $\beta < 1$, and vice versa $\beta > 1$
	γ	Cost coefficient, which acts on the extra cost paid by other enterprises for industrial chain value synergy, when there are fewer barriers to industrial data or scene sharing, there is $\gamma < 1$, and vice versa $\gamma > 1$

Table 2: Tripartite game payment matrix.

Strategy portfolio	Revenue of government	Profit of leader enterprises	Profit of other enterprises
Fulfillment, assumption, and cooperation	$U_1 + U_1' + \Delta U_1 - G_0 - G - G_e - G_s$	$U_2 + \alpha kD + G_e - C_e - \beta\Delta C_e$	$U_3 + (1-\alpha)kD + G_s - C_s - \gamma\Delta C_s$
Fulfillment, assumption, and noncooperation	$U_1 + U_1' - G_0 - G - G_e$	$U_2 + G_e - C_e - \beta\Delta C_e$	$U_3 - C_s + N_2$
Fulfillment, nonassumption, and cooperation	$U_1 + U_1' - G_0 - G - G_s$	$U_2 - g - C_e + N_1$	$U_3 + G_s - C_s - \gamma\Delta C_s$
Fulfillment, nonassumption, and noncooperation	$U_1 + U_1' - G_0 - G$	$U_2 - g - C_e$	$U_3 - C_s$
Nonfulfillment, assumption, and cooperation	$U_1 + \Delta U_1' - G_0$	$U_2 + \alpha kD' - C_e - \Delta C_e$	$U_3 + (1-\alpha)kD' - C_s - \Delta C_s$
Nonfulfillment, assumption, noncooperation	$U_1 - G_0$	$U_2 - C_e - \Delta C_e$	$U_3 - C_s + N_2'$
Nonfulfillment, nonassumption, and cooperation	$U_1 - G_0$	$U_2 - C_e + N_1$	$U_3 - C_s - \Delta C_s$
Nonfulfillment, nonassumption, and noncooperation	$U_1 - G_0$	$U_2 - C_e$	$U_3 - C_s$

4.2. Evolutionary Stabilization Strategy Solution Based on Replicated Dynamic Equations. Based on the analysis mentioned above, the replicated dynamic equations for the government, chain leader enterprises, and other enterprises are discussed as follows.

4.2.1. The Replicated Dynamics Equation for the Government

$$\begin{aligned} F(x) &= \frac{dx}{dt} \\ &= \left(E_{g1} - E_{g2}\right)x(1-x) \\ &= \left[U_1{}' + yz\left(\Delta U_1 - \Delta U_1{}'\right)G - yG_e - zG_s\right]x(1-x), \end{aligned} \tag{4}$$

when $z = z_1 = G + y_1 G_e - U_1{}'/y_1(\Delta U1 - \Delta U_1') - G_s$, $F(x)$ is constantly equal to 0. At this point, the equation is in a stable state regardless of any value of x.

When $z \neq z_1$, let $F(x) = 0$. It is easy to see that $x = 0$ and $x = 1$ are the two stable points of the equation about x. To find the derivative of $F(x)$, $F'(x) = (1-2x)[U_1{}' + yz(\Delta U_1 - \Delta U_1{}') - G - yG_e - zG_s]$. The following discussion is based on the subcase of z taking values.

(1) When $z > z_1$, there are $F'(x)|_{x=0} > 0$, $F'(x)|_{x=1} < 0$, and then $x = 1$ is a stable strategy
(2) When $z < z_1$, there are $F'(x)|_{x=0} < 0$, $F'(x)|_{x=1} > 0$, and then $x = 0$ is a stable strategy

The phase diagram of government's strategic evolution is shown in Figure 1.

4.2.2. The Replicated Dynamic Equation of the Chain Leader Enterprise

$$\begin{aligned} F(y) &= \frac{dy}{dt} \\ &= (E_{s1} - E_{s2})y(1-y) \\ &= \left[xz\alpha kD + xG_e - x\beta\Delta C_e + (1-x)z\alpha kD' - (1-x)\Delta C_e + xg - xzN_1 - (1-x)zN_1{}'\right]y(1-y), \end{aligned} \tag{5}$$

when $z = z_2 = -x_2 g + (x_2\beta + 1 - x_2)\Delta C_e - x_2 G_e/x_2\alpha kD + (1-x_2)\alpha kD' - x_2 N_1 - (1-x_2)N_1{}'$ and $F(y)$ is constantly equal to 0, when the equation is in a stable state regardless of any value of y.

When $z \neq z_2$, such that $F(y) = 0$, it is easy to see that $y = 0$ and $y = 1$ are two stable points of the equation about y. $F'(y) = (1-2y)[xz\alpha kD + xG_e - x\beta\Delta C_e + (1-x)z\alpha kD' - (1-x)\Delta C_e + xg - xzN_1 - (1-x)zN_1{}']$; depending on the value of z, the following two cases exist:

(1) When $z > z_2$, there are $F'(y)|_{y=0} > 0$, and $F'(y)|_{y=1} < 0$, i.e., $y = 1$ is a stable strategy
(2) When $z < z_2$, there are $F'(y)|_{y=0} < 0$, and $F'(y)|_{y=1} > 0$, i.e., $y = 0$ is a stable strategy

The phase diagram of the chain leader enterprises' strategic evolution is shown in Figure 2.

4.2.3. The Replication Dynamic Equation for Other Enterprises in the Chain

$$\begin{aligned} F(z) &= \frac{dz}{dt} \\ &= \left[xy(1-\alpha)kD + xG_s - (1-x)y(1-\alpha)kD' - (1-x+xy)\Delta C_s - xyN_2 - (1-x)yN_2{}'\right]z(1-z), \end{aligned} \tag{6}$$

when $x = x_3 = \Delta C_s + y_3(1-\alpha)kD' + y_3 N_2{}'/y_3(1-\alpha)k(D - D') + (1-\gamma)\Delta C_s - y_3(N_2 - N_2{}')$, $F(z)$ is constantly equal to 0. At this time, the equation is in a stable state regardless of any value of z.

When $x \neq x_3$, let $F(z) = 0$. It is easy to know that $z = 0$ and $z = 1$ are the two stable points of the equation about z.

(1) When $x > x_3$, there are $F'(z)|_{z=0} > 0$, and $F'(z)|_{z=1} < 0$, i.e., $z = 1$ is a stable strategy
(2) When $x < x_3$, there are $F'(z)|_{z=0} < 0$, and $F'(z)|_{z=1} > 0$, i.e., $z = 0$ is a stable strategy

The phase diagram of other enterprises' strategic evolution is shown in Figure 3.

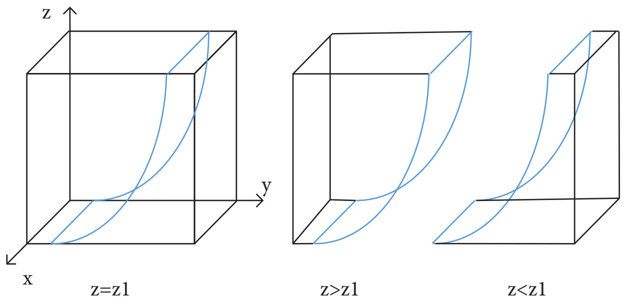

Figure 1: Phase diagram of government's strategic evolution.

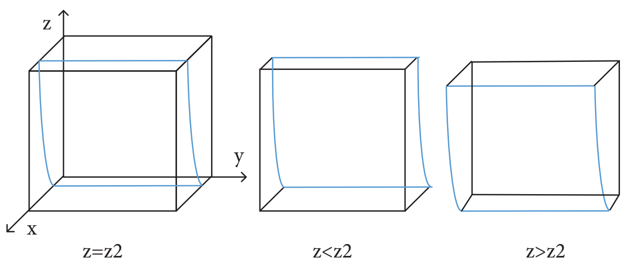

Figure 2: Phase diagram of the chain leader enterprises' strategic evolution.

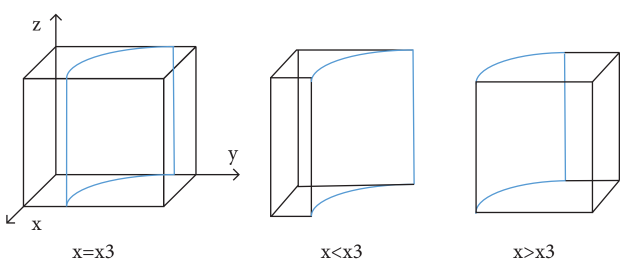

Figure 3: Phase diagram of other enterprises' strategic evolution.

4.3. Stability Analysis of the Equilibrium Point. As Ritzberger and Weibull pointed out, the progressive stability of multigroup evolutionary games must only analyze eight equilibrium points: (0, 0, 0), (1, 1, 1), (0, 0, 1), (1, 1, 0), (0, 1, 0), (0, 1, 0), (1, 0, 0), and (1, 0, 1). Let $F(x)$, $F(y)$, and $F(z)$ be constantly equal to 0. The mixed strategy Nash equilibrium points are (x, y_1, z_1), (x_2, y, z_2), and (x_3, y_3, z). Since the mixed strategy equilibrium points are saddle points and must not be evolutionarily stable equilibria, this study only discusses the local stability of the seven pure strategic equilibrium points. The Jacobi matrix is obtained according to the replica dynamic equation as $J=[J_1, J_2, J_3]$, $J_1=[(1-2x)[U_1{}' + yz(\Delta U_1 - \Delta U_1{}') - G - yG_e - zG_s]$, $y(1-y)[z\alpha k(D-D') + G_e + (1-\beta)\Delta C_e + g - z(N_1 - N_1{}')]$, $z(1-z)[y(1-\alpha)k(D-D') + G_s + (1-\gamma)\Delta C_s - y(N_2 - N_2{}')]]^T$, $J_2=[x(1-x)[z(\Delta U_1 - \Delta U_1{}') - G_s]$, $(1-2y)[xz\alpha kD + xG_e - x\beta\Delta C_e + (1-x)z\alpha kD' - (1-x)\Delta C_e + xg - xzN_1 - (1-x)zN_1{}']$, $z(1-z)[x(1-\alpha)kD + (1-x)(1-\alpha)kD' - xN_2 - (1-x)N_2{}']]^T$, $J_3=[x(1-x)[y(\Delta U_1 - \Delta U_1{}') - G_e]$, $y(1-y)[x\alpha kD + (1-x)\alpha kD') - xN_1 - (1-x)N_1{}']$, and $(1-2z)[xy(1-\alpha)kD + xG_s - (1-x)y(1-\alpha)kD' - (1-x+x\gamma)\Delta C_s - xyN_2 - (1-x)yN_2{}']^T$.

In this study, we utilize the Lyapunov indirect method to examine the local stability of the equilibrium point. If all the real parts of the characteristic roots of the Jacobi matrix are negative, the equilibrium point is considered asymptotically stable. On the other hand, if there are positive real parts in the characteristic roots of the Jacobi matrix, the equilibrium point is unstable. Lastly, if there are zero real parts in the characteristic roots of the Jacobi matrix and no real parts are positive, it is impossible to determine the stability of the equilibrium point. The stability of the equilibrium point situation can be observed in Table 3. We have discovered that (1, 1, 1) and (0, 1, 1), (1, 0, 1) and (1, 0, 0), and (1, 1, 0) and (1, 0, 0) are a pair of equilibrium points, each with mutually exclusive stability conditions, and the stability conditions of each equilibrium point are analyzed below.

Condition 1. When $\Delta U_1{}' < U_1{}' + \Delta U_1 - (G + G_e + G_s)$, $\beta\Delta C_e - g + N_1 < \alpha kD + G_e$ and $\gamma\Delta C_s + N_2 < (1-\alpha)kD + G_s$ are satisfied simultaneously. When the net potential gain from fulfillment exceeds the net potential gain from industrial chain value synergy in a nonfulfillment situation, the government will pursue the fulfillment strategy. Chain leader enterprises will choose to assume responsibility when the sum of the incremental share of benefits from assuming responsibilities and the government's policy support exceeds the difference between the cost of cooperation and the opportunity cost of nonassumption. Other enterprises will choose to cooperate with the industrial chain value synergy when the sum of the revenue and the government's policy support is greater than the sum of the cooperation cost and the free-riding benefits. When these conditions are met, the final strategy evolution results tend to be (1, 1, 1), leading to the establishment of a stable "chain chief system" for industrial chain value synergy.

Condition 2. When $\Delta U_1{}' > U_1{}' + \Delta U_1 - (G + G_e + G_s)$, $\Delta C_e + N_1{}' < \alpha kD'$, $\Delta C_s + N_2{}' < (1-\alpha)kD'$ is satisfied at the same time. It is known that Conditions 1 and 2 cannot be met at the same time. If the potential benefits of spontaneous cooperation among enterprises in the chain exceed those of fulfilling the government's duty as the chain chief, the government will pursue a nonfulfillment strategy. However, if the benefits of actively cooperating with the "chain chief system" exceed the costs of cooperation and free riding, both leading and other enterprises in the chain will choose to adopt the active cooperation strategy. Condition 2 leads to a dynamic game in which the government fails to fulfill its role as the chain chief, and the leading and other enterprises spontaneously engage in industry chain cooperation, with the final strategy evolution tending toward the stability point (0, 1, 1).

Condition 3. When $G + G_s < U_1{}'$, $\alpha kD + G_e < \beta\Delta C_e - g + N_1$ and $\gamma\Delta C_s < G_s$ are satisfied simultaneously. The government will opt for the fulfillment strategy only when the marginal benefit of serving as the chain chief outweighs the total cost of investing in the chain and supporting nonleading enterprises. Leading enterprises in the chain will choose the nonassumption strategy if the total share of income

Table 3: Analysis of the stability of the equilibrium point.

Equilibrium point	Jacobi matrix eigenvalues λ_1, λ_2, and λ_3	Real part symbol	Local stability
(1, 1, 1)	$-U_1' - \Delta U_1 + \Delta U_1' + G + G_e + G_s$, $-\alpha kD - G_e + \beta\Delta C_e - g + N_1$, and $\gamma\Delta C_s - G_s - (1-\alpha)kD + N_2$	(∗, ∗, ∗)	Stable with conditions
(1, 1, 0)	$-U_1' + G + G_e$, $-G_e + \beta\Delta C_e - g$, and $-\gamma\Delta C_s + G_s + (1-\alpha)kD - N_2$	(∗, ∗, ∗)	Stable with conditions
(1, 0, 1)	$-U_1' + G + G_s$, $\alpha kD + G_e - \beta\Delta C_e + g - N_1$, and $\gamma\Delta C_s - G_s$	(∗, ∗, ∗)	Stable with conditions
(0, 1, 1)	$U_1' + \Delta U_1 - \Delta U_1' - G - G_e - G_s$, $-\alpha kD' + \Delta C_e + N_1'$, and $\Delta C_s - (1-\alpha)kD' + N_2'$	(∗, ∗, ∗)	Stable with conditions
(0, 1, 0)	$U_1' - G - G_e$, ΔC_e, and $-\Delta C_s + (1-\alpha)kD' - N_2'$	(−, +, ∗)	Unstable
(1, 0, 0)	$-U_1' - G$, $G_e - \beta\Delta C_e + g$, and $G_s - \gamma\Delta C_s$	(−, ∗, ∗)	Stable with conditions
(0, 0, 1)	$U_1' - G - G_s$, $\alpha kD' - (1-\beta)\Delta C_e - N_1'$, and ΔC_s	(∗, ∗, +)	Unstable
(0, 0, 0)	$U_1' - G$, $-\Delta C_e$, and $-\Delta C_s$	(∗, −, −)	Stable with conditions

Note. *represents the real part of the symbol to be determined.

generated by the chain leader role and the government's subsidy for that role is less than the difference between the cost of taking on that role and the opportunity cost of not taking it on. For other enterprises in the chain, if the government's incentives and subsidies for synergy outweigh the cost of cooperation, they will cooperate with the synergy. When Condition 3 is met, the result of the dynamic game is that the government actively takes on the role of chain chief, the leading enterprise does not, and other enterprises cooperate with the synergy. This results in the stable equilibrium point of (1, 0, 1) in the final strategy evolution.

Condition 4. When $G_e < \beta\Delta C_e$-g, $G_s < \gamma\Delta C_s$ is satisfied at the same time. Conditions 3 and 4 are a pair of mutually exclusive conditions. When the incentives and subsidies for assuming chain leader responsibilities are less than the difference between the extra cost of cooperation and the penalty for not assuming chain leader responsibilities. When the government's incentives and subsidies for synergy are less than the cost of cooperation for the other enterprises in the chain, the final strategy evolution result is that the government selects the fulfillment strategy, but the enterprises in the chain choose not to carry out the chain collaboration under the "chain chief system," the final strategy evolves to the point of stability (1, 0, 0).

Condition 5. When $G + G_e < U_1{'}$, $\beta\Delta C_e - g < G_e$ and $G_s + (1-\alpha)kD - N_2 < \gamma\Delta C_s$ are satisfied simultaneously. Conditions 4 and 5 are a pair of mutually exclusive conditions. If the incremental basic benefit from fulfilling its duty exceeds the sum of the common cost of investing in building the chain and the cost of supporting the chain's leading enterprises, the government will select the fulfillment strategy. If the reward and subsidy for assuming responsibility exceed the difference between the extra cost of cooperation and the penalty for not assuming responsibility, the leading enterprises will choose to assume chain leader responsibility. If the net benefit of the "chain chief system" is less than the cost of cooperation, the other enterprises in the chain will choose not to cooperate. The outcome of the dynamic game will tend to converge on a stable point (1, 1, 0).

Condition 6. When $U_1{'} < G$, the basic income increment of the government's long-term obligation is less than the average cost of the investment in the industrial chain's building, the dynamic game evolution results in the evolution of a state in which the government, chain leader enterprises, and other enterprises all select a negative strategy, tending to the stability point (0, 0, 0).

5. Simulation Analysis

To verify the validity of local equilibrium stability in evolutionary games, numerical simulations are conducted using Matlab2012a, analyzing how the variation of the cost and benefit parameters and coefficients affect the evolutionary outcomes. The discussion contains two sections: first, the parameter issue, which includes the government's input, penalty measure, and the free-riding benefits of two different types of enterprises, and then, the coefficient issue, which includes the revenue coefficient k, the revenue allocation coefficient α, and cost coefficients β and γ.

5.1. Analysis of Changes in Cost and Benefit Parameters. According to the relationship of the parameters in the variable description section and with reference to the actual situation of the high-tech industry development in Guangzhou, the initial values of the parameters in this study are set as $U_1{'} = 40$, $\Delta U_1 = 80$, $\Delta U_1{'} = 65$, $g = 10$, $D = 160$, $D' = 80$, $\Delta C_e = 25$, $\Delta C_s = 15$, $\alpha = 0.6$, $k = 1$, $\beta = 1$, $\gamma = 1$, $N_1 = 8$, $N_1{'} = 10$, $N_2 = 6$, $N_2{'} = 8$. This study will mainly analyze the impact of each cost and benefit parameter change on the evolutionary results under the parameter setting of condition one. Firstly, we will analyze the cost of the government's investment in building a "chain chief system" for synergy when the government does its duty as the chain chief G, G_e, G_s. The impact on the evolutionary game process and the outcome is analyzed by changing the relative values of G, G_e, G_s. First we let $G = 20, G_e = 18, G_s = 12$, second we increase the cost of public input and let $G = 35, G_e = 10, G_s = 5$, then we increase the subsidies to the chain leader enterprise and let $G = 5, G_e = 30, G_s = 5$. The simulation results of the corresponding replicated dynamic equation system evolving 50 times are shown in Figure 4.

When government spending is more equal between public inputs, supporting chain leader enterprises and other enterprises, other enterprises are more likely to choose the strategy of cooperation; when the government chooses to mainly support chain-owning firms, the evolution of the probability of other firms choosing cooperation is slower but less significant; while when government spending is mainly public inputs to industries, the evolution of the probability of chain leader enterprises choosing to assume responsibility changes significantly and there is an inflection point. It can be inferred that the government can appropriately increase the proportion of subsidies to the chain leader enterprises.

Next, we modify the numerical value of the government's punitive measure g. Let g be 5, 10, and 20, respectively, which means the penalty measure decreases gradually, and the simulation results of the corresponding replicated dynamic equation system evolving 50 times are shown in Figure 5. Because of the presence of g, the evolutionary results of all enterprises in the chain gradually evolve from a tendency to choose not to take responsibility and cooperate to cooperation, while the probability of chain leader enterprises assuming responsibility increases as the penalty measure g increases, while the probability of other enterprises participating in the chain chief system's cooperation decreases. Therefore, it is beneficial for the government to appropriately increase the punishment measures for uncooperative or inaction by chain leaders to encourage chain leader enterprises to assume the responsibility of leading the industrial chain coordination.

Controlling the other parameters constant, the relative magnitude between the free-riding benefits and the cooperative gain is modified. We consider three cases, the free-

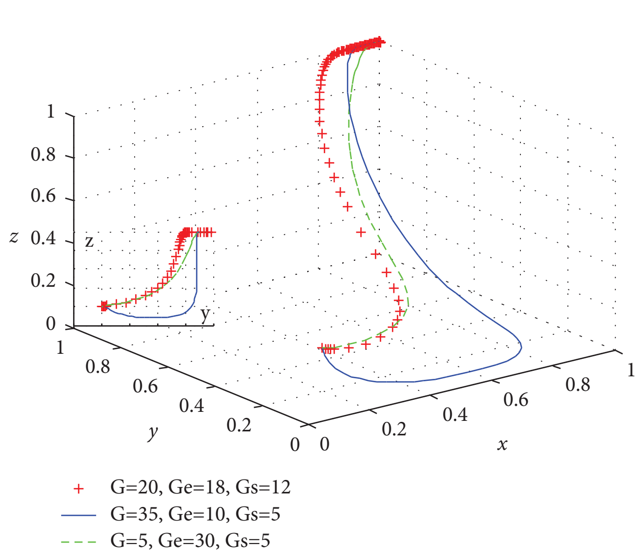

FIGURE 4: Effect of the government's input G, G_e, G_s on the evolutionary game process and outcome.

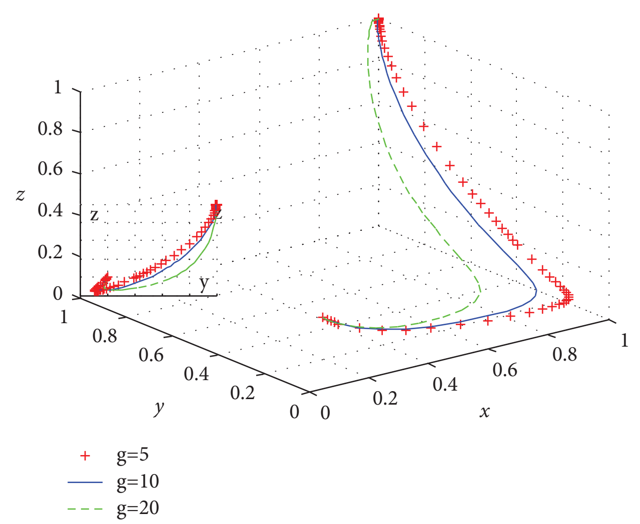

FIGURE 5: Effect of penalty measure g on the evolutionary game process and outcome.

riding benefits of enterprises in the industrial chain is far less than the cooperative benefit (let $N_1 = 10$, $N_1{}' = 15$, $N_2 = 5$, and $N_2{}' = 10$), the free-riding benefits of other enterprises in the chain are larger (let $N_1 = 10$, $N_1{}' = 12$, $N_2 = 25$, and $N_2{}' = 30$), and the free-riding benefits of chain leader enterprises in the chain are larger (let $N_1 = 30$, $N_1{}' = 35$, $N_2 = 5$, and $N_2{}' = 10$). The simulation results for the corresponding set of replicated dynamic equations evolving 50 times are shown in Figure 6.

Due to the existence of the free-riding benefits, the evolutionary results of all enterprises in the chain evolve from a tendency of negative strategy gradually, i.e., there is an inflection point in the trend of y, z. When the free-riding benefits of other enterprises increase, the probability of cooperation under the "chain chief system" is smaller than in the third case, and in the second case, the evolution rate

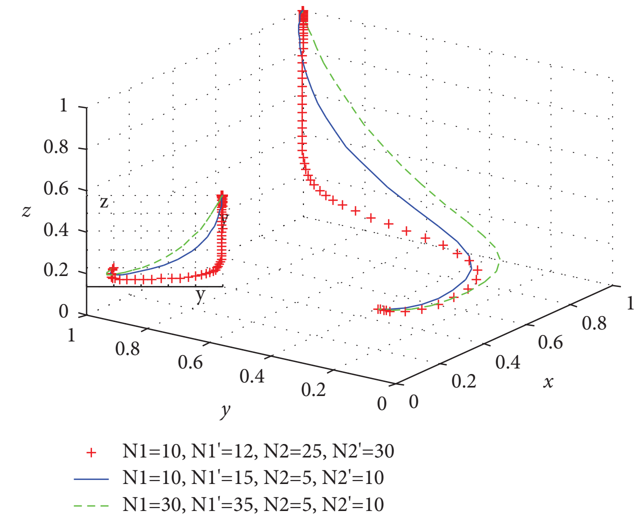

FIGURE 6: Effect of the free-riding benefits on the evolutionary game process and outcome.

of z to probability 1 is slower than that of y to probability 1. Conversely, when the free-riding benefits of the chain leader enterprises increase, their probability of assuming responsibility will be much smaller than in the other two scenarios. Therefore, when the free-riding benefits are greater than the gain from cooperation, enterprises in the chain will choose a wait-and-see strategy, and the government needs to restrain the free-riding behavior of enterprises in the synergy through regulation and other means.

5.2. Analysis of the Changes in Cost and Benefit Coefficients. We modify the parameter k which represents the industry risk and cooperation environment and other factors evolve from favorable to less favorable to industry cooperation (let $k = 1$, $k = 0.7$, and $k = 0.3$) and analyze the changes of the evolutionary game. The simulation results of the corresponding replicated dynamic equation system evolving 50 times are shown in Figure 7. It can be seen that as the revenue coefficient k increases, the probability of enterprises in the industry chain assuming responsibility and cooperating both increases faster and the probability of other enterprises cooperating increases faster than that of the chain leader enterprises. Since factors such as industry risk and cooperation environment objectively vary among different industries, to compensate for the impact of too small a revenue coefficient on the synergy and combining mutually exclusive expressions of Conditions 1 and 5 at the same time $G_s + (1 - \alpha)kD - N_2 < \gamma \Delta C_s$, therefore, to motivate other enterprises to cooperate with the "chain chief system," the government needs to increase the subsidies to other enterprises appropriately.

We suppose that the benefits generated by the synergy are increasingly distributed to chain leader enterprises (let $\alpha = 0.3,\ 0.6,\ 0.95$), the corresponding replicated dynamic equation system evolves 50 times, and the simulation results are shown in Figure 8.

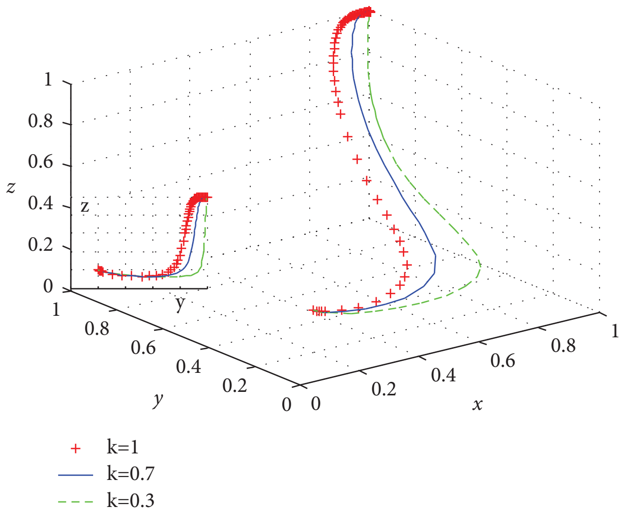

Figure 7: Effect of revenue coefficient k on the evolutionary game process and outcome.

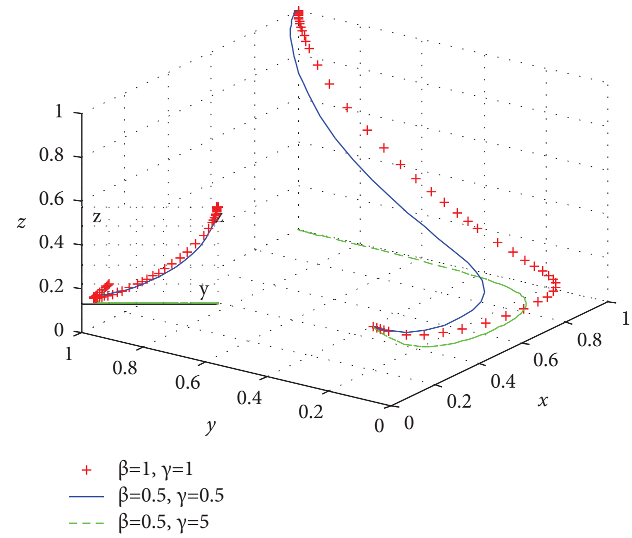

Figure 9: Effect of cost coefficients β and γ on the evolutionary game process and outcome.

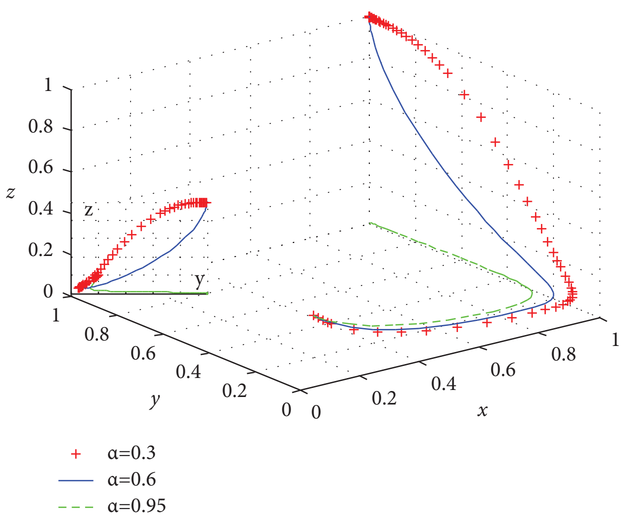

Figure 8: Effect of revenue allocation coefficient α on the evolutionary game process and outcome.

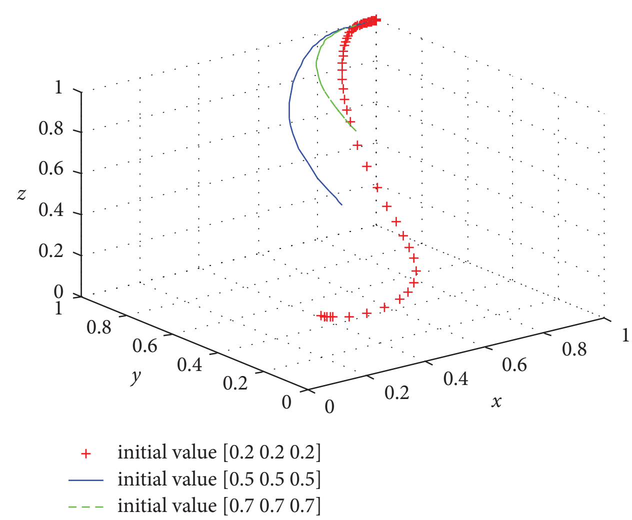

Figure 10: Simulation evolution results of modifying the initial values of x, y, and z.

It can be seen that when $\alpha = 0.3$ and $\alpha = 0.6$, the parameters satisfy Condition 1, and the stable strategies of the evolving game are (1, 1, 1), and the "chain chief system" industrial chain value synergy is established. With the increase of α, the probability of other enterprises selecting the "cooperation" strategy slows down. When α continues to increase to 0.95, the parameter satisfies Condition 3, other enterprises select the noncooperation strategy, and the evolutionarily stable strategy is (1, 1, 0). That is, as the industry concentration increases, the leading enterprises will get most of the cooperation benefits in the synergy, other enterprises will have difficulty getting the expected cooperation benefits, and it will be much more difficult to establish the "chain chief system" synergy.

Let (β, γ) be equal to (1.1), (0.5, 0.5), and (0.5, 5), respectively, i.e., the cases where the industry data and the sharing barriers are large, small, and large cost coefficients for other enterprises in the industry chain only. According to reality, this analysis does not cover instances where cost coefficients are high for only leading enterprises. The simulation results of the corresponding set of replicated dynamic equations evolving 50 times are shown in Figure 9.

In the case of satisfying Condition 1 from $(\beta, \gamma) = (1, 1)$ to $(\beta, \gamma) = (0.5, 0.5)$, the decision of the chain leader enterprises reaches the inflection point faster as the sharing barrier decreases. In the $(\beta, \gamma) = (0.5, 5)$ case, that is, the law, policy, and industrial environment cause the cost coefficient of the chain leader enterprise to be small and the cost coefficient of other enterprises to be large, putting other enterprises at a disadvantage in the sharing of data and scenarios. When the parameters meet Condition 5, the government fulfills its duty as the chain chief, and the leading enterprises assume the responsibility of the chain leader, but other enterprises do not cooperate with the "chain chief system" for industry chain value synergy.

In the case of satisfying Condition 1, this study also modifies the initial values of the evolution of x, y, and z, and let (x, y, z) be (0.2, 0.2, 0.2), (0.5, 0.5, 0.5) and (0.7, 0.7, 0.7), respectively. It can be seen that the final evolutionary equilibrium points are all points (1, 1, 1), as shown in Figure 10.

6. Conclusions

6.1. Conclusion. In this study, we approach the matter of creating synergistic value in industrial chains by proposing the "chain chief system" as the responsibility structure. We construct a three-party evolutionary game model comprising the government, chain leader enterprises, and other enterprises to analyze the system. The government's role in the chain is to regulate and guide synergy through taxation and policymaking. The process and results of synergy benefits generated by the government as the chain chief, major leading enterprises as the chain leader, and other enterprises reflect the value created by the synergy. Through evolutionary stability analysis, we identify six possible outcomes of the evolutionary game under certain conditions. The evolutionary stability measure of the game of synergistic value creation of each subject under the "chain chief system" is purely strategic. By combining the government's responsibility as the chain chief, the leading enterprises' responsibility as chain leader, and the participation of other enterprises in cooperation, the "chain chief system" can generate maximum synergistic benefits and cocreate value within the chain.

6.2. Implications. This study makes theoretical contributions in three significant ways. First, it interprets the "chain chief system" industrial chain responsibility system from the perspective of synergistic value creation, where the government's role is critical, enriching the related research of the "chain chief system." Our model's results show that the government's leadership in the industry chain's development through credit endorsement and unified resource allocation leads to greater synergistic value creation benefits. Additionally, the characteristics of industries affect the distribution of synergistic benefits among different types of enterprises and thus impact the effect of enterprise synergy. Second, we introduce the value synergy of industrial chains under the "chain chief system" based on organizational trust and free-riding behavior. As resource sharing forms the foundation of synergy, the existence of free-riding behavior in synergistic value creation will influence the synergistic benefits generated by industrial chain cooperation. Third, we utilize an evolutionary game model to investigate the interaction among industry chain subjects and enrich research on game theory from the perspective of value synergy among the government, leading enterprises, and other enterprises in the industry chain.

The practical insights of this study are reflected in the following three areas:

Initially, the government must shoulder both coordination and incentive responsibilities when it comes to industrial chain coordination. To bolster regional characteristic industries and leading industries, the government must make the most of its limited resources by improving the precision of policy implementation, tailoring "one policy for one chain" for industrial chain coordination based on the peculiarities of each industry. To maximize the potential of the incentive function, the government should grant chain leaders with additional support. Enabling chain leader enterprises to exert their influence without any limitations is most advantageous for the establishment of industrial chain coordination within the "chain chief system." Therefore, it is suggested that the government aid leading enterprises in exporting their know-how to the industrial chain based on industry data and scene-specific advantages. Furthermore, it is advisable to augment penalty measures for chain leaders who are uncooperative or inactive, while designing a market surveillance mechanism that reduces free-riding conduct in industrial chain coordination.

Second, when constructing the "chain chief system" industrial chain value synergy, industry traits must be taken into account. In cases where the hurdles to benefits and costs rise, the advantages of cooperation plummet and the expenses of cooperation escalate, leading enterprises to adopt antagonistic strategies. Hence, it would be more favorable for the government to mitigate the barriers to data sharing and scene sharing by utilizing policy methods and establishing digital empowerment mechanisms. It can also heighten its public goods supply function and compensate for the structural deficiencies of the innovation system to create the "chain chief system" industrial chain value synergy ecosystem. To accomplish this objective, the government is advised to implement corresponding policies, such as laws and regulations on intellectual property, protocols on data sharing and scene sharing among enterprises, and lowering the obstacles to cooperation. Furthermore, constructing a unified data sharing and exchange platform and an Internet of Things platform, promoting enterprises to the cloud and platform, providing standardized and unified data resources and services to enterprises along the industrial chain, and lowering the hurdles to data and information sharing are other possible steps that can be taken.

Third, industry concentration will influence the ultimate strategy choice regarding industrial chain value synergy. If the top enterprises in the industry chain capture most of the revenue, the cooperation income for other enterprises will be significantly lower than the cooperation cost, which will lead to these enterprises abstaining from industrial chain value synergy. Thus, it is incumbent upon the government to assume a regulatory function and guarantee that the cooperation revenue is not excessively concentrated and allocated to the leading enterprises. It is also crucial to implement rigorous anticorruption measures.

6.3. Deficiencies and Future Prospects. This research endeavors to scrutinize the effects of the "chain chief system," a chain responsibility framework, on industrial chain value synergy at the meso level. It selects several significant variables, including the government's penalty severity, the magnitude of subsidies for different enterprises, and the impact of industry traits on the synergy effect. In this investigation, the division of synergistic advantages between chain leader enterprises and other companies in the industry is used to illustrate industry traits. In today's digitization-influenced milieu, the extent of digitalization can also serve as an essential dimension to depict industry traits, which could be employed as a variable for future researchers. The initial values utilized in this analysis are grounded in Guangzhou city's development. Since diverse cities have diverse industrial chain construction statuses, distinct initial values could be set in the future to observe various evolutionary directions and game outcomes and further extrapolate the evolutionary path of industrial chain value synergy.

Data Availability

This study uses the method of numerical stimulation; if it is necessary, we can provide the code later.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] F. Sahin and E. P. Robinson, "Flow coordination and information sharing in supply chains: review, implications, and directions for future research," *Decision Sciences*, vol. 33, no. 4, pp. 505–536, 2002.
[2] O. Bar-Gill, "Behavioural economics of consumer contracts," *Minnesota Law Review*, vol. 92, no. 2, p. 749, 2008.
[3] J. McNerney, B. D. Fath, and G. Silverberg, "Network structure of inter-industry flows," *Physica A: Statistical Mechanics and its Applications*, vol. 392, no. 24, pp. 6427–6441, 2013.
[4] Research Group of the Institute of Industrial Economics of CASS, "The theoretical connotation of the central enterprise as the chain leader of industry chain and the function realization," *China Industrial Economics*, vol. 412, no. 7, pp. 5–24, 2022.
[5] S. J. Lin and H. F. Ni, "The Chinese-style industrial chain'chain chief system': theoretical connotation and practical significance," *Social Sciences in Yunnan*, vol. 248, no. 4, pp. 90–101, 2022.
[6] J. Ruggie, "Protect, respect and remedy: a framework for business and human rights," *Innovations: Technology, Governance, Globalization*, vol. 3, no. 2, pp. 189–212, 2008.
[7] I. Manners, "Normative power europe: a contradiction in terms?" *Journal of Communication and Media Studies: Journal of Common Market Studies*, vol. 40, no. 2, pp. 235–258, 2002.
[8] A. R. Young, "Liberalizing trade, not exporting rules: the limits to regulatory co-ordination in the EU's "new generation" preferential trade agreements," *Journal of European Public Policy*, vol. 22, no. 9, pp. 1253–1275, 2015.
[9] J. Harrison, M. Barbu, L. Campling, B. Richardson, and A. Smith, "Governing labour standards through free trade agreements: limits of the European union's trade and sustainable development chapters," *Journal of Communication and Media Studies: Journal of Common Market Studies*, vol. 57, no. 2, pp. 260–277, 2018.
[10] O. Osiyevskyy and J. Dewald, "Explorative versus exploitative business model change: the cognitive antecedents of firm-level responses to disruptive innovation," *Strategic Entrepreneurship Journal*, vol. 9, no. 1, pp. 58–78, 2015.
[11] J. E. Austin and M. M. Seitanidi, "Collaborative value creation: Part I Value creation spectrum and collaboration stages," *Nonprofit and Voluntary Sector Quarterly*, vol. 41, no. 5, pp. 726–758, 2012.
[12] J. E. Austin and M. M. Seitanidi, "Collaborative value creation: a review of partnering between nonprofits and businesses. Part 2: partnership processes and outcomes," *Nonprofit and Voluntary Sector Quarterly*, vol. 41, no. 6, pp. 929–968, 2012.
[13] S. Yin and B. Li, "A stochastic differential game of low carbon technology sharing in collaborative innovation system of superior enterprises and inferior enterprises under uncertain environment," *Open Mathematics*, vol. 16, no. 1, pp. 607–622, 2018.
[14] H. Sun, Y. Wan, L. Zhang, and Z. Zhou, "Evolutionary game of the green investment in a two-echelon supply chain under a government subsidy mechanism," *Journal of Cleaner Production*, vol. 235, pp. 1315–1326, 2019.
[15] M. Wang, S. Lian, S. Yin, and H. Dong, "A three-player game model for promoting the diffusion of green technology in manufacturing enterprises from the perspective of supply and demand," *Mathematics*, vol. 8, no. 9, pp. 1585–1626, 2020.
[16] K. Yi, "Can vertical specialization explain the growth of world trade?" *Journal of Political Economy*, vol. 111, no. 1, pp. 52–102, 2003.
[17] J. Li, R. Sikora, M. J. Shaw, and G. Woo Tan, "A strategic analysis of inter organizational information sharing," *Decision Support Systems*, vol. 42, no. 1, pp. 251–266, 2006.
[18] M. G. Jacobides and C. J. K. Tae, "Kingpins, bottlenecks, and value dynamics along a sector," *Organization Science*, vol. 26, no. 3, pp. 889–907, 2015.
[19] M. Luqman, U. Soytas, Y. Li, and N. Ahmad, "Rewards and penalties in an evolutionary game theoretic model of international environmental agreements," *Economic Research-Ekonomska Istrazivanja*, vol. 35, pp. 1–20, 2021.
[20] M. H. Chen, H. Wei, M. Wei, H. Huang, and C. H. Su, "Modeling a green supply chain in the hotel industry: an evolutionary game theory approach," *International Journal of Hospitality Management*, vol. 92, Article ID 102716, 2021.
[21] W. Gu, L. Wei, W. Zhang, and X. Yan, "Evolutionary game analysis of cooperation between natural resource- and energy-intensive companies in reverse logistics operations," *International Journal of Production Economics*, vol. 218, pp. 159–169, 2019.
[22] A. Gharaei, M. Karimi, and S. A. Hoseini Shekarabi, "An integrated multi-product, multi-buyer supply chain under penalty, green, and quality control polices and a vendor managed inventory with consignment stock agreement: the outer approximation with equality relaxation and augmented penalty algorithm," *Applied Mathematical Modelling*, vol. 69, pp. 223–254, 2019.
[23] J. M. Wu and C. Shao, "Research on formation mechanism of industry chain: '4+4+4' model," *China Industrial Economics*, vol. 4, pp. 36–43, 2006.

[24] Y. H. Yu, "Type of industrial chain and the benchmark of industrial chain efficiency," *China Industrial Economics*, vol. 11, pp. 35–42, 2005.

[25] J. H. Dyer and H. Singh, "The relational view: cooperative strategy and sources of interorganizational competitive advantage," *Academy of Management Review*, vol. 23, no. 4, pp. 660–679, 1998.

[26] P. Ganotakis and J. H. Love, "The innovation value chain in new technology-based firms: evidence from the U.K," *Journal of Product Innovation Management*, vol. 29, no. 5, pp. 839–860, 2012.

[27] N. Luu, L. V. Ngo, and J. Cadeaux, "Value synergy and value asymmetry in relationship marketing programs," *Industrial Marketing Management*, vol. 68, pp. 165–176, 2018.

[28] X. Wang, B. Z. Li, S. Yin, and J. W. Zeng, "Formation mechanism for integrated innovation network among strategic emerging industries: analytical and simulation approaches," *Computers & Industrial Engineering*, vol. 162, Article ID 107705, 2021.

[29] Z. Liu, W. Li, L. Geng et al., "The effective market and responsible government in strategic industry management: practice and optimization strategy of chain chief system," *Cell discovery*, vol. 8, no. 1, pp. 6–72, 2022.

[30] N. G. Mankiw, M. Weinzierl, and D. Yagan, "Optimal taxation in theory and practice," *SSRN Electronic Journal*, vol. 20, 2009.

[31] A. B. Atkinson and J. E. Stiglitz, "The design of tax structure: direct versus indirect taxation," *Journal of Public Economics*, vol. 6, no. 1-2, pp. 55–75, 1976.

[32] N. G. Mankiw, M. Weinzierl, and D. Yagan, "Optimal taxation in theory and practice," *The Journal of Economic Perspectives*, vol. 23, no. 4, pp. 147–174, 2009.

[33] J. Liu, X. H. Wang, and T. Liu, "Behavior choice mechanisms and tax incentive mechanisms in the game of construction safety," *Buildings*, vol. 12, no. 8, p. 1078, 2022.

[34] C. E. Bai, Y. J. Du, Z. G. Tao, and Y. T. Tong, "Determinants and trends of local protectionism and regional concentration of industries," *Economic Research*, vol. 4, pp. 29–40, 2004.

[35] S. T. Li, Y. Z. Hou, Y. Z. Liu, and B. Chen, "An investigation and analysis of the domestic local protection problem in China," *Economic Research*, vol. 11, pp. 78–84+95, 2004.

[36] Y. Tian, K. Govindan, and Q. Zhu, "A system dynamics model based on evolutionary game theory for green supply chain management diffusion among Chinese manufacturers," *Journal of Cleaner Production*, vol. 80, pp. 96–105, 2014.

[37] J. I. Lewis and R. H. Wiser, "Fostering a renewable energy technology industry: an international comparison of wind industry policy support mechanisms," *Energy Policy*, vol. 35, no. 3, pp. 1844–1857, 2007.

[38] R. Adner and D. Levinthal, "Demand heterogeneity and technology evolution: implications for product and process innovation," *Management Science*, vol. 47, no. 5, pp. 611–628, 2001.

[39] R. M. Solow, "A contribution to the theory of economic growth," *Quarterly Journal of Economics*, vol. 70, no. 1, pp. 65–94, 1956.

[40] K. J. Arrow, "The economic implications of learning by doing," *The Review of Economic Studies*, vol. 29, no. 3, pp. 155–173, 1962.

[41] C. F. Phillips and F. M. Scherer, "Industrial market structure and economic performance," *Bell Journal of Economics and Management Science*, vol. 2, no. 2, p. 683, 1971.

[42] K. J. Arrow, "Economic welfare and the allocation of resources for invention," *The Rate and Direction of Inventive Activity*, vol. 26, pp. 609–626, 1962.

[43] L. B. Lave and E. Mansfield, "Industrial research and technological innovation; an econometric analysis," *Econometrica*, vol. 40, no. 1, pp. 207–209, 1972.

[44] M. M. Cornett, O. Erhemjamts, and H. Tehranian, "Competitive environment and innovation intensity," *Global Finance Journal*, vol. 41, pp. 44–59, 2019.

[45] M. Hitt, R. E. Hoskisson, and R. D. Ireland, "A mid-range theory of the interactive effects of international and product diversification on innovation and performance," *Journal of Management*, vol. 20, no. 2, pp. 297–326, 1994.

[46] S. Yin and Y. Y. Yu, "An adoption-implementation framework of digital green knowledge to improve the performance of digital green innovation practices for industry 5.0," *Journal of Cleaner Production*, vol. 33, 2022.

[47] A. Urbinati, D. Chiaroni, V. Chiesa, and F. Frattini, "The role of digital technologies in open innovation processes: an exploratory multiple case study analysis," *R & D Management*, vol. 50, no. 1, pp. 136–160, 2018.

[48] S. E. Ibrahim, M. H. Fallah, and R. R. Reilly, "Localized sources of knowledge and the effect of knowledge spillovers: an empirical study of inventors in the telecommunications industry," *Journal of Economic Geography*, vol. 9, no. 3, pp. 405–431, 2008.

[49] C. Xu, W. Fan, C. Wang, and Z. Xin, "Risk and intellectual property in technical standard competition: a game theory perspective," *China Communications*, vol. 11, no. 5, pp. 136–143, 2014.

[50] J. Xue, R. Gong, L. Zhao, X. Ji, and Y. Xu, "A green supply-chain decision model for energy-saving products that accounts for government subsidies," *Sustainability*, vol. 11, no. 8, p. 2209, 2019.

[51] Y. L. Zheng, S. M. Liu, and C. G. Bai, "A comparative study of industrial common technology R&D models considering the participation of multiple subjects," *Chinese Journal of Management Science*, vol. 29, no. 8, pp. 44–56, 2021.

[52] X. Zhao, Y. Xue, and L. Ding, "Implementation of low carbon industrial symbiosis systems under financial constraint and environmental regulations: An evolutionary game approach," *Journal of Cleaner Production*, vol. 277, Article ID 124289, 2020.

[53] Z. Guo, J. Zhen, Y. Qu, and H. Ren, "The possibility of China's industrial park management committee to promote interenterprise cooperative innovation in the park: a trilateral evolutionary game perspective," *Complexity*, vol. 2020, Article ID 7462706, 14 pages, 2020.

[54] Y. Han, H. Zheng, Y. Huang, and X. Li, "Considering consumers' green preferences and government subsidies in the decision making of the construction and demolition waste recycling supply chain: a stackelberg game approach," *Buildings*, vol. 12, no. 6, 2022.

[55] R. D. Raut, H. V. Bhasin, and S. S. Kamble, "Analysing the effect of uncertain environmental factors on supplier-buyer strategic partnership (SBSP) by using structural equation model (SEM)," *International Journal of Procurement Management*, vol. 5, no. 2, pp. 202–228, 2012.

[56] D. A. Johnston, D. M. McCutcheon, F. I. Stuart, and H. Kerwood, "Effects of supplier trust on performance of cooperative supplier relationships," *Journal of Operations Management*, vol. 22, no. 1, pp. 23–38, 2004.

[57] K. Celuch, J. H. Bantham, and C. J. Kasouf, "The role of trust in buyer-seller conflict management," *Journal of Business Research*, vol. 64, no. 10, pp. 1082–1088, 2011.

[58] S. Ganesan, "Determinants of long-term orientation in buyer-seller relationships," *Journal of Marketing*, vol. 58, no. 2, pp. 1–19, 1994.

[59] J. Yang, *The Generation Mechanism of Inter-firm Trust in Supply Chain and its Impact on Cooperation*, Zhejiang University, Hangzhou, China, 2006.
[60] M. Sako and S. Helper, "Determinants of trust in supplier relations: evidence from the automotive industry in Japan and the United States," *Journal of Economic Behavior & Organization*, vol. 34, no. 3, pp. 387–417, 1998.
[61] L. Wang and C. Guo-hong, "A game analysis on the technology innovation of chain-style industrial cluster," *Chinese Journal of Management Science*, vol. 24, no. 1, pp. 151–158, 2016.
[62] N. Yan, Y. Zhang, X. Xu, and Y. Gao, "Online finance with dual channels and bidirectional free-riding effect," *International Journal of Production Economics*, vol. 231, Article ID 107834, 2021.
[63] F. Bernstein, J.-S. Song, and X. Zheng, "Free riding in a multichannel supply chain," *Naval Research Logistics*, vol. 56, no. 8, pp. 745–765, 2009.
[64] Q. L. He, H. J. Tang, X. Luo, and X. J. Wang, "Evolutionary game analysis of agricultural non-point source pollution coordinated governance by government, agricultural enterprise and farmers," *Chinese Journal of Management Science*, vol. 18, 2023.
[65] X. H. Yang and C. Liu, "Evolutionary game of OFDI enterprises' fighting alone and win-win cooperation innovation: from the perspective of manufacturing enterprises," *East China Economic Management*, vol. 36, no. 12, pp. 98–109, 2022.
[66] S. Yin, N. Zhang, K. Ullah, and S. Gao, "Enhancing digital innovation for the sustainable transformation of manufacturing industry: a pressure- state-response system framework to perceptions of digital green innovation and its performance for green and intelligent manufacturing," *Systems*, vol. 10, no. 3, p. 72, 2022.
[67] A. Hafezalkotob, "Competition of two green and regular supply chains under environmental protection and revenue seeking policies of government," *Computers & Industrial Engineering*, vol. 82, pp. 103–114, 2015.
[68] S. Barari, G. Agarwal, and M. K. Tiwari, "A decision framework for the analysis of green supply chain contracts: an evolutionary game approach," *Expert Systems with Applications*, vol. 39, no. 3, pp. 2965–2976, 2012.
[69] K. Li, D. J. Kim, K. R. Lang, R. J. Kauffman, and M. Naldi, "How should we understand the digital economy in asia? critical assessment and research agenda," *Electronic Commerce Research and Applications*, vol. 15, 2020.
[70] J. Lee and N. Berente, "Digital innovation and the division of innovative labor: digital controls in the automotive industry," *Organization Science*, vol. 23, no. 5, pp. 1428–1447, 2012.
[71] Y. F. Pan, Y. B. Lv, P. B. Fu, and L. Chen, "Study on the game mechanism and strategies in energy industry integration," *Science of Science and Management of S. & T.*, vol. 31, no. 6, pp. 171–174, 2010.
[72] C. B. Ho, S. Hsu, and K. B. Oh, "Knowledge sharing: game and reasoned action perspectives," *Industrial Management & Data Systems*, vol. 109, no. 9, pp. 1211–1230, 2009.
[73] R. Normann and R. Ramírez, "From value chain to value constellation: designing interactive strategy," *Harvard Business Review*, vol. 71, no. 4, pp. 65–77, 1993.
[74] J. T. Mentzer, W. DeWitt, J. S. Keebler et al., "Defining supply chain management," *Journal of Business Logistics*, vol. 22, no. 2, pp. 1–25, 2001.
[75] J. Chen, Z. Yang, and Z. Q. Zhu, "The theoretical logic, implementation mode and application scenario of the new type of national system," *Reform*, vol. 5, pp. 1–17, 2021.
[76] Y. Han, H. Zheng, Y. Huang, and X. Li, "Considering consumers' green preferences and government subsidies in the decision making of the construction and demolition waste recycling supply chain: a stackelberg game approach," *Buildings*, vol. 12, no. 6, p. 832, 2022.
[77] S. Liu, W. Jiang, X. Li, and X.-F. Zhou, "Lyapunov stability analysis of fractional nonlinear systems," *Applied Mathematics Letters*, vol. 51, pp. 13–19, 2016.