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Co-Evolutionary Dynamics of Mission-Oriented Innovation Consortia and Future Industries

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Abstract

By constructing a system dynamics (SD) model of how mission-oriented innovation consortia empower the development of future industries, this study reveals the internal causal structure and dynamic evolution mechanism of the system in the process of multi-actor collaborative innovation. The results show that, throughout the simulation period, innovation consortia exert a sustained positive enabling effect on the development of future industries, mainly reflected in the expansion of industrial market demand, the accumulation of core technology breakthroughs, and the increase in the added value of the future industrial chain. Value co-creation intensity, patent resource complementarity, and technological adaptability jointly constitute the key mechanisms through which innovation consortia empower future industries. These mechanisms are coupled through multiple feedback paths, thereby maintaining the continuous evolutionary momentum of the system. From a system dynamics perspective, this study characterizes the dynamic interaction process and nonlinear evolutionary features between innovation consortia and future industry development, enriches the relevant theoretical framework, and provides a dynamic simulation basis for policy design related to future industries.

Keywords: innovation consortia; future industries; value co-creation; collaborative innovation; patent resource complementarity

1. Introduction

Against the backdrop of an accelerated transformation in global high-tech paradigms, innovation has become a fundamental driving force for industrial upgrading, technological paradigm shifts, and the restructuring of complex industrial ecosystems [1,2]. However, as an important carrier of the new round of technological revolution and industrial transformation, future industries are inherently characterized by high technological uncertainty, market volatility, and systemic complexity. It is increasingly difficult for a single firm to independently bear the innovation resources, organizational capabilities, and trial-and-error costs required for long-term technological breakthroughs [3]. As technological boundaries become increasingly blurred, collaborative innovation among heterogeneous actors has gradually become an important mechanism for addressing systemic uncertainty and promoting the evolution of socio-technical systems [4].

In this context, multi-actor innovation consortia, as a form of cross-organizational and cross-domain collaborative innovation, have attracted increasing scholarly attention [5].

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This study does not focus on market-oriented R&D alliances in a general sense, but rather on mission-oriented innovation consortia in the context of major national strategic technological tasks. Such consortia are guided by national strategic tasks and aim to achieve core technology breakthroughs and cultivate future industries. Through government guidance, leading-firm organization, support from universities and research institutions, and collaboration among upstream and downstream actors in the industrial chain, they integrate dispersed knowledge, technologies, and innovation resources. Compared with traditional R&D alliances, mission-oriented innovation consortia combine strategic orientation, organizational coordination, and public risk sharing. They can help bridge the transformation gap between technological supply and industrial demand in highly uncertain technological contexts [6], thereby promoting core technology breakthroughs and upgrading the industrial value chain.

The research context of this study focuses on future industries driven by the evolution of general-purpose technologies, including technology-intensive fields such as next-generation artificial intelligence, large model ecosystems, and humanoid robots [7]. These future industries are usually characterized by intensive frontier R&D investment, unstable technological trajectories, immature industrial chain support systems, delayed commercialization returns, and sensitivity to external shocks. In particular, during the transition from laboratory research to pilot testing and then to large-scale industrial application, future industries often face significant technology transfer delays and the "valley of death" problem [8]. Therefore, their development cannot rely entirely on spontaneous market mechanisms. Instead, mission-oriented innovation consortia are needed at critical points to conduct strategic resource orchestration, cross-domain knowledge recombination, and collaborative technology transfer [9].

Although existing studies have examined multi-actor collaborative innovation and its organizational governance, there remains insufficient explanation of how mission-oriented innovation consortia dynamically empower the evolution of future industries. Most existing studies adopt static analytical frameworks, case narratives, or partial governance perspectives, focusing on the formation motives, governance structures, or collaboration modes of innovation consortia [10–12]. Traditional strategic management and alliance theories can effectively explain the initial motivations for why innovation consortia are formed [10,13,14], but they provide limited explanations of the long-term dynamic feedback mechanisms among internal value co-creation intensity, resource allocation, technological collaboration, collaborative resistance, and external shocks. Therefore, the causal feedback structure, multi-loop nonlinear interactions, and cumulative delay effects through which innovation consortia empower future industry development remain to be further characterized.

From the perspective of socio-technical system transition, future industries are not simply an aggregation of isolated industrial categories. Rather, they should be understood as complex adaptive systems jointly shaped by policy guidance, knowledge circulation, technological adaptability, market diffusion, and organizational learning [15]. Their evolutionary process features strong nonlinearity, path dependence, and reinforcing feedback. Traditional linear regression models or static game frameworks are insufficient for capturing system-level interactions among heterogeneous actors under long-cycle delays and multiple feedback effects. To address these limitations, this study introduces the system dynamics (SD) method and constructs a dynamic simulation model of how mission-oriented innovation consortia empower future industry development. The model incorporates national strategic support, value co-creation intensity, patent resource complementarity, collaborative innovation efficiency, and collaborative resistance into a unified analytical framework, so as to reveal the dynamic mechanism through which innovation consortia drive the evolutionary transition of future industries.

The marginal contributions of this study are mainly reflected in three aspects. First, at the theoretical level, this study defines mission-oriented innovation consortia as complex adaptive collaborative systems that support the evolution of future industries. It emphasizes the dynamic coupling among national strategic support, micro-level collaborative resistance, and uncertainty in future industries, thereby extending the explanatory boundary of mission-oriented innovation governance research. Second, at the methodological level, this study introduces an SD simulation framework to characterize multiple feedback loops, structural delays, and nonlinear cumulative mechanisms in the process through which innovation consortia empower future industry development, thus addressing the limitations of existing static analytical methods in explaining long-term dynamic evolution. Third, at the practical level, this study provides systematic implications for government departments and industry-leading enterprises to optimize the governance of future industries. It helps identify key policy levers, improve cross-organizational coordination mechanisms, and enhance the adaptability and resilience of future industry innovation systems.

2. Literature Review and Theoretical Framework

2.1. Conceptual Definition and Review of Related Studies

Mission-oriented innovation consortia are important organizational carriers in micro-level industrial innovation practices [13]. To clarify the boundary of the research object, this study distinguishes mission-oriented innovation consortia from ordinary market-oriented R&D alliances and traditional industry–university–research alliances. Although all three types of organizations involve cross-actor collaborative innovation, they differ significantly in driving logic, value orientation, organizational boundaries, risk sharing, and modes of achievement transformation (see Table 1). Compared with ordinary market-oriented R&D alliances, mission-oriented innovation consortia are not driven solely by short-term commercial returns, but also carry national strategic objectives, industrial chain security objectives, and future technological competition objectives. Compared with traditional industry–university–research alliances, their organizational boundaries are more open, their coordination levels are more complex, and fiscal support, institutional coordination, and technology transfer mechanisms are more prominent.

Table 1. Comparison of heterogeneous innovation alliances.

Dimension	Ordinary Market-Oriented R&D Alliance	Traditional Industry–University–Research Alliance	Mission-Oriented Innovation Consortia
Driving core	market interests and technological complementarity	staged project cooperation and university achievement transformatio	dual drive of national strategic objectives and market mechanisms
Value orientation	short-term commercial returns and partial competitive advantage	knowledge spillover, talent cultivation, and paper or patent outputs	core technology breakthroughs, industrial chain value, and future industry cultivation
Organizational boundary	relatively clear boundaries, mainly based on contractual alliances	relatively loose boundaries, mostly point-to-point horizontal cooperation	dynamic embedding across actors, fields, and stages, with strong vertical coordination

Table 1. *Cont.*

Dimension	Ordinary Market-Oriented R&D Alliance	Traditional Industry–University–Research Alliance	Mission-Oriented Innovation Consortia
Risk sharing	mainly borne by alliance members, with relatively low risk preference	mainly borne by universities or research actors, with high uncertainty in achievement transformation	shared by public finance, leading enterprises, and research actors, oriented toward highly uncertain frontier technologies
Transformation characteristics	mainly incremental technological improvement, with a relatively short commercialization cycle	transformation gaps easily arise between laboratory achievements and production lines	crossing the "valley of death" through full-life-cycle collaboration and pilot-scale transformation mechanisms
Applicable context	technological improvement and product development in mature industries	university achievement transformation and general industry–university–research cooperation	core technology breakthroughs, strategic emerging industries, and future industry cultivation

Therefore, the mission-oriented innovation consortia examined in this study refer to cross-organizational, cross-domain, and cross-stage collaborative innovation networks guided by national strategic tasks. They are usually led by leading enterprises, chain-leading enterprises, or key platform organizations, and involve universities, research institutions, government departments, technology intermediary agencies, and upstream and downstream enterprises in the industrial chain. These actors collaborate around core technology breakthroughs, major industrial bottlenecks, and the cultivation of future industries. The process through which they empower future industry development is essentially a dynamic evolutionary process jointly shaped by national strategic support, market incentives, organizational coordination, technological adaptability, and industrial value creation.

Specifically, the uniqueness of mission-oriented innovation consortia is mainly reflected in three aspects. First, their objective function is strategic. They not only pursue economic returns, but also undertake tasks such as catching up in key technologies, maintaining industrial chain security, and cultivating future industries. Second, their organizational structure is complex. They need to form a network structure that combines vertical coordination and horizontal collaboration among government, enterprises, universities, research institutions, and technology intermediary agencies. Third, their evolutionary process is nonlinear. It is driven by positive mechanisms such as fiscal expenditure, knowledge sharing, and patent resource complementarity, while also being constrained by negative mechanisms such as interest conflict, collaborative resistance, and external technological shocks.

Therefore, mission-oriented innovation consortia are not merely an extension of general innovation alliances. Rather, they are a new type of innovation organization characterized by embedded strategic objectives, complex organizational networks, significant technology transfer delays, and multiple feedback mechanisms. If the theoretical frameworks of ordinary market-oriented R&D alliances or traditional industry–university–research alliances are directly applied, the distinctive features of mission-oriented innovation consortia, such as strong strategic guidance, long technological delays, high organizational complexity, and public risk sharing, may be overlooked, resulting in insufficient explanation of the evolution of future industries. This constitutes the entry point of this study: under the high uncertainty of future industries, how mission-oriented innovation consortia generate enabling effects through mechanisms such as national strategic support, value

co-creation intensity, patent resource complementarity, collaborative innovation efficiency, and technological adaptability.

On the other hand, the future industries examined in this study are emerging industrial forms driven by frontier technological breakthroughs, located in the incubation stage or the early stage of industrialization, and characterized by high technological uncertainty, market uncertainty, and paradigm-disrupting potential. Their development usually involves long R&D cycles, unstable technological trajectories, incomplete industrial chain support, and delayed commercialization returns. Therefore, such industries are not merely extensions of mature industries in a general sense, but strategic industrial forms that rely more heavily on original innovation, interdisciplinary knowledge integration, and organized technological breakthroughs. Accordingly, the relationship between mission-oriented innovation consortia and future industries is not a simple input–output relationship, but rather involves multiple mechanisms such as multi-actor collaboration, knowledge flows, technology diffusion, market traction, and reinforcing feedback.

Existing studies on the above issues mainly focus on the following three aspects:

First, studies on mission-oriented innovation policy and innovation alliance governance. As mission-oriented innovation policy has received increasing attention, related research has gradually shifted from the analysis of traditional industrial policy tools to the organizational mechanism through which national strategic objectives are transformed into cross-actor collaborative actions [16]. Existing literature emphasizes that mission-oriented innovation policy can promote collaborative innovation among governments, enterprises, universities, and research institutions around major technological objectives through strategic task setting, public resource allocation, and risk-sharing mechanisms [17]. These studies provide an important theoretical basis for understanding national strategic support, fiscal expenditure, and organizational coordination. However, existing studies focus more on macro-level policy design, the role of the public sector, or the selection of strategic missions [18], while paying insufficient attention to the micro-level operating mechanisms within mission-oriented innovation consortia. In particular, mission-oriented innovation consortia are characterized by strong actor heterogeneity, large differences in objective functions, complex intellectual property allocation, and high coordination costs, which may easily give rise to interest conflict, opportunistic behavior, and free-riding behavior [19,20]. Existing literature still provides limited dynamic characterization of how these internal frictions affect collaborative innovation efficiency, core technology breakthroughs, and long-term industrial evolution.

Second, studies on the formation mechanisms and evolutionary paths of future industries. Future industries are characterized by high frontier orientation, high uncertainty, high investment intensity, and high growth potential. Their formation usually depends on original technological breakthroughs, technical standards setting, application scenario expansion, and the cultivation of industrial market demand [21]. Existing studies often explain the formation logic of such industries from the perspectives of industrial policy, technology roadmaps, innovation ecosystem construction, and industrial chain layout [22]. The development of future industries is not a linear expansion process [23], but is jointly affected by technological maturity, market acceptance, capital investment, standards competition, and industrial collaboration. Although related studies have recognized the uncertainty and nonlinearity of future industry development, they still provide insufficient explanation of how mission-oriented innovation consortia cross transformation gaps through resource integration, patent resource complementarity, technology transfer, and value co-creation intensity. A dynamic analytical framework capable of capturing delays, feedback, and cumulative effects remains lacking.

Third, studies on the application of system dynamics in innovation governance and industrial evolution. The system dynamics method is well suited for dealing with complex system problems such as multi-actor interaction, multiple feedback loops, structural delays, and nonlinear accumulation, and has been widely applied to research contexts such as technology diffusion, R&D input–output, industry–university–research collaboration, industrial ecosystem evolution, and innovation system resilience [24]. Existing studies show that system dynamics can reveal the dynamic relationships among R&D investment, knowledge accumulation, technology transfer, and market diffusion through causal loop diagrams, stock–flow diagrams, and integral equations [25]. Compared with traditional static models, system dynamics is therefore more suitable for analyzing evolutionary features such as long-term accumulation, stage transition, and reinforcing feedback in industrial development [26]. However, existing system dynamics studies mostly focus on general innovation systems or market-oriented R&D alliances [27], and rarely incorporate mission-oriented innovation consortia into the analytical framework. At the same time, existing models usually emphasize the positive effect of innovation input on output growth, while paying relatively insufficient attention to the dynamic trade-offs among national strategic support, internal collaborative resistance, external technological shocks, and system resilience.

In summary, previous studies provide an important foundation for understanding mission-oriented innovation consortia, future industry evolution, and system dynamics modeling, but three limitations remain. First, in terms of research objects, existing literature mainly discusses ordinary market-oriented R&D alliances or loose industry–university–research cooperation, and has not sufficiently revealed the unique attributes of mission-oriented innovation consortia in national strategic guidance, public risk sharing, and core technology breakthroughs. Second, in terms of mechanisms, existing studies emphasize the positive effects of resource input, knowledge sharing, and technology diffusion, but pay insufficient attention to constraining mechanisms such as interest conflict, free-riding behavior, and collaborative resistance. Third, in terms of research methods, most studies remain at the level of static mechanism analysis or partial empirical testing, and lack dynamic simulation that places national strategic support, micro-level organizational frictions, technology transfer delays, and future industry evolution within a unified feedback system. Based on these gaps, this study introduces the system dynamics method and constructs a dynamic simulation model of how mission-oriented innovation consortia empower future industry development, so as to reveal their endogenous feedback structure, key mechanisms, and nonlinear evolutionary patterns.

2.2. Integrated Multi-Theoretical Framework

The process through which mission-oriented innovation consortia empower future industry development is not determined by a single factor, but is jointly shaped by organizational structure, factor flows, actor behavior, and system evolution [28]. Triple helix theory can explain the organizational coordination structure among government, enterprises, universities, and research institutions. Innovation ecosystem theory can explain the circulation and complementarity of knowledge, technology, capital, and patent resources in multi-actor networks. Dynamic capability theory can explain how alliance members sense, absorb, and reconfigure external technological and market changes. Complex adaptive system theory can explain nonlinear feedback, delay effects, and system transitions in the evolution of future industries. Therefore, this study integrates these theories into a four-level analytical framework (see Figure 1) to support the subsequent design of variables and feedback loops.

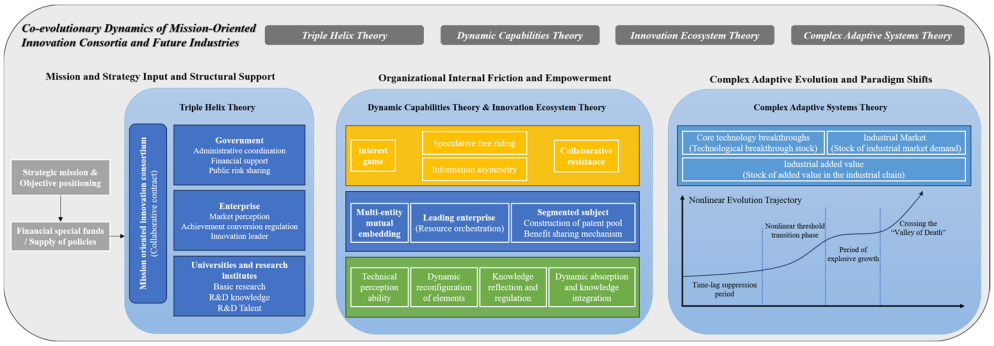


Figure 1. Integrated multi-theoretical framework.

2.2.1. Triple Helix Theory

Triple helix theory holds that interactions among government, industry, and universities constitute a collaborative network centered on knowledge production and innovation diffusion. The overlap and nesting among the three spheres can generate new "hybrid organizations", thereby forming new innovation modes [29]. This theory breaks through the assumption of fixed divisions of labor among government, enterprises, and universities in traditional linear innovation models, and emphasizes role overlap, functional complementarity, and organizational embedding among the three types of actors. According to this theory, enterprises, universities and research institutions, and governments are no longer isolated actors. Instead, they jointly promote knowledge production, achievement transformation, and industrial upgrading [30].

For mission-oriented innovation consortia, enterprises promote technology transfer based on market demand, application scenarios, and industrialization capabilities [31]; universities and research institutions support core technology breakthroughs through basic research, talent supply, and original innovation capabilities [32]; and governments provide directional guidance through national strategic task setting, policy supply, and fiscal expenditure [33]. The coordination among these three types of actors constitutes the organizational foundation of mission-oriented innovation consortia. Triple helix theory mainly explains the organizational boundary and initial structure of mission-oriented innovation consortia. Specifically, the government helix provides strategic guidance and institutional resources, the enterprise helix provides market demand and industrialization capabilities, and the university and research institution helix provides knowledge production and technological sources. Their collaboration provides the basic driving force for subsequent core technology breakthroughs and the increase in added value of the future industrial chain. The system dynamics variables derived from this theory include national strategic support, government support, fiscal expenditure, university investment, scientific talent, original research outputs, technology transfer, and demand for industry–university–research collaboration.

2.2.2. Dynamic Capabilities Theory

Dynamic capability theory emphasizes that, in uncertain environments, organizations need to sense opportunities, integrate resources, and reconfigure capabilities to maintain competitive advantage [34]. Unlike the static resource-based view, dynamic capability theory focuses on adaptive behavior when organizations face technological change, market change, and external shocks [35,36]. The future industry context faced by mission-oriented innovation consortia is highly uncertain. Technological trajectories have not yet stabilized, market demand has not yet matured, and industrial chain support systems are still undergoing dynamic adjustment. Therefore, resource input alone cannot guarantee the development of future industries. The key lies in whether alliance actors can effectively

absorb external knowledge, reconfigure R&D resources, improve collaborative innovation efficiency, and enhance technological adaptability [37].

Within mission-oriented innovation consortia, enterprises improve enterprise R&D efficiency through value co-creation intensity and collaborative R&D; universities and research institutions enhance technological sources through knowledge spillover and technological outcome supply; and governments and intermediary agencies reduce coordination costs through institutional coordination and transformation platforms. This process reflects the mechanism through which multiple actors jointly form dynamic capabilities. The stronger the dynamic capabilities are, the better the alliance can transform frontier technologies into core technology breakthroughs, and further form product differentiation, technological leadership, and market expansion capabilities. Based on this theory, system dynamics variables such as enterprise R&D efficiency, collaborative innovation efficiency, value co-creation intensity, technological adaptability, technological leadership, product differentiation, and system resilience can be proposed. These variables jointly constitute the behavioral mechanisms in the system.

2.2.3. Innovation Ecosystem Theory

Innovation consortia can be regarded as open, self-organizing, and nonlinear "biology-like systems" [38]. According to innovation ecosystem theory, innovation is realized in open, complementary, and dynamically evolving ecosystems. Different innovation actors form collaborative networks around common value goals through the exchange of knowledge, capital, data, patents, and technologies [39]. In such systems, enterprises, universities, research institutions, technology intermediaries, and government departments are not isolated nodes. Rather, they form interdependent ecological structures through resource complementarity, knowledge sharing, and value co-creation.

This theory can explain the relationships among patent resource complementarity, technical standards setting, and industrial chain value creation. Through the establishment of innovation consortia, differentiated knowledge, patents, and technological capabilities held by different actors can be integrated into shared technology platforms and patent pools. The complementarity of patents and technological elements supports material circulation, while the coupling between enterprise capabilities and industrial demand promotes niche matching and stimulates technological adaptability [40]. At the same time, the improvement of patent resource complementarity and the expansion of the scale of patent pool size further promote innovation ecosystem coordination and core technology breakthroughs [41]. Technology intermediary agencies and intellectual property protection mechanisms can reduce uncertainty in the technology transfer process and promote the diffusion of technological achievements from laboratories to the industrial chain. Accordingly, system dynamics variables such as value co-creation intensity, patent resource complementarity, scale of patent pool size, technology intermediary policy, intellectual property protection, technology transfer, product competitive advantage, and added value of the future industrial chain can be proposed. These variables jointly constitute the factor circulation mechanism within the system and help explain how innovation consortia transform dispersed knowledge resources, technological resources, and patent resources into driving forces for future industry development.

2.2.4. Complex Adaptive Systems Theory

Complex adaptive system theory argues that a system consists of multiple adaptive actors [42], and that continuous interaction, learning, and feedback among actors generate nonlinear evolutionary processes. In complex systems, local actor behaviors may accumulate through feedback mechanisms into system-level emergent outcomes. System

evolution often exhibits path dependence, delay effects, stage transitions, and nonlinear growth [43]. The development of future industries has precisely such complex adaptive system attributes. In the early stage, it requires long-term R&D accumulation and trial and error; in the middle stage, it depends on core technology breakthroughs and scenario diffusion; and in the later stage, it may experience rapid expansion of industrial market demand and leaps in industrial chain value.

Therefore, the process through which mission-oriented innovation consortia empower future industry development is not a linear input–output process. On the one hand, national strategic support, value co-creation intensity, patent resource complementarity, and collaborative innovation efficiency can promote core technology breakthroughs, market demand expansion, and the increase in added value of the future industrial chain through reinforcing feedback. On the other hand, interest conflict, free-riding behavior, and collaborative resistance can form negative feedback or disturbance mechanisms, suppressing system growth and altering evolutionary paths. In this sense, complex adaptive system theory provides the basis for introducing the system dynamics method in this study.

In summary, the above theories provide theoretical support for this study from four levels: organizational structure, resource factors, actor behavior, and system evolution. These theories are not simply parallel to one another, but jointly constitute the logical chain through which mission-oriented innovation consortia empower future industry development. National strategic tasks form the organizational foundation through the triple helix coordination structure; alliance actors realize resource reconfiguration, technological adaptability, and collaborative response through dynamic capabilities; and knowledge, technology, patents, and market resources circulate and complement one another within the innovation ecosystem. Ultimately, multiple reinforcing feedback and negative regulating mechanisms jointly shape the nonlinear evolutionary path of future industry development, laying a solid theoretical foundation for multi-scenario comparative simulation.

3. System Dynamics Model Construction

Future industry development is affected by multiple factors such as national strategic support and knowledge transfer, and these factors are coupled with one another. Traditional analytical methods based on a single causal chain or static equilibrium assumptions are insufficient for revealing the dynamic evolutionary patterns through which mission-oriented innovation consortia empower future industry development. The system dynamics method emphasizes system structure, feedback loops, stock accumulation, and delay effects, and is therefore suitable for characterizing nonlinear evolutionary mechanisms involving multiple actors.

3.1. System Boundaries and Basic Assumptions

Mission-oriented innovation consortia are regarded as complex adaptive systems composed of multiple actors, including leading enterprises, universities and research institutions, government departments, technology intermediary agencies, and upstream and downstream enterprises in the industrial chain. These actors interact through mechanisms such as strategic task guidance, fiscal support, technology transfer, and patent resource complementarity. Therefore, this study defines the system boundary as a semi-open system. It not only focuses on endogenous feedback processes such as strategic mission driving, value co-creation, knowledge transfer, market expansion, and industrial value creation, but also considers the constraining effects of collaborative resistance and technological shocks on system evolution. Based on this boundary, the following basic assumptions are proposed.

Assumption 1. *Mission-oriented innovation consortia are characterized by national strategic guidance. Driven by national strategic objectives, government departments provide directional guidance through strategic task setting, policy supply, and fiscal support. Leading enterprises or chain-leading enterprises act as core organizers that integrate heterogeneous resources from universities, research institutions, technology intermediary agencies, and upstream and downstream enterprises in the industrial chain. Unlike market-oriented alliances that mainly pursue short-term profits, mission-oriented innovation consortia prioritize resource allocation toward core technology breakthroughs, industrial chain security, and the cultivation of future industries.*

Assumption 2. *The system boundary is semi-open. Future industry development does not take place in a closed environment. External shocks such as international technological decoupling, shortages of key components, abrupt changes in policy environments, and contraction of market capital may affect technological adaptability, technology transfer, and industrial value creation. This study summarizes external shocks as effective technological shock impact and introduces them into the model through scenario variables, so as to examine system resilience and shock mitigation capability.*

Assumption 3. *The collaborative innovation process is constrained by internal friction. Although mission-oriented innovation consortia share common goals such as value co-creation, resource complementarity, and technological breakthroughs, different actors may still differ in objective functions and face problems such as information asymmetry, conflicts over intellectual property allocation, and unequal benefit sharing. The resulting interest conflict, opportunistic behavior, and free-riding behavior may further generate collaborative resistance and weaken collaborative innovation efficiency.*

Assumption 4. *System evolution involves structural delays. In mission-oriented innovation consortia, there are obvious time delays from strategic task setting and R&D resource input to core technology breakthroughs, and further to market demand expansion and the increase in added value of the industrial chain. Therefore, this study introduces two delay parameters into the model: the delay in R&D achievement transformation and the delay in technical standards and market diffusion. These parameters are used to characterize the lag effects in the transformation of scientific and technological input into core technology breakthroughs, and in the transformation of core technology breakthroughs into market diffusion and industrial chain value creation.*

3.2. Causal Relationship Construction

Considering the flow of knowledge, technology, and innovation resources among multiple actors, mission-oriented innovation consortia form a complex collaborative network. Taking mission-oriented innovation consortia as the core organizational carrier, this study incorporates national strategic support, value co-creation, patent resource complementarity, collaborative innovation efficiency, technological adaptability, internal friction, and external shocks into a unified analytical framework. The causal structure constructed on this basis reveals the endogenous feedback mechanisms through which mission-oriented innovation consortia empower future industry development.

The model contains the following major feedback loops:

(1) Strategic Mission–Technology Breakthrough Loop (R1)

National Strategic Support → Government Support (+) → Fiscal Expenditure (+) → Technology Investment from Universities and Research Institutions (+) → Scientific Talent (+) → Original Research Outputs (+) → Patent Resource Complementarity (+) → Scale of Patent Pool Size (+) → Core Technology Breakthroughs (+) → Added Value of the Future Industrial Chain (+) → Regional Economic Growth (+) → Demand for Industry–University–Research Collaboration (+) → Mission-Oriented Innovation Consortia (+) → National Strategic Support.

(2) Value Co-creation–Enterprise Innovation Loop (R2)

Mission-Oriented Innovation Consortia → Value Co-creation Intensity (+) → Enterprise R&D Efficiency (+) → Enterprise Innovation Output (+) → Patent Resource Complementarity (+) → Core Technology Breakthroughs (+) → Added Value of the Future Industrial Chain (+) → Regional Economic Growth (+) → Demand for Industry–University–Research Collaboration (+) → Mission-Oriented Innovation Consortia.

(3) Knowledge Transfer–Collaborative Innovation Loop (R3)

Mission-Oriented Innovation Consortia → University Investment (+) → University Innovation Vitality (+) → University Technological Outcomes (+) → Technology Intermediary Policy (+) → Intellectual Property Protection (+) → Technology Transfer (+) → Collaborative Innovation Efficiency (+) → Patent Resource Complementarity (+) → Core Technology Breakthroughs (+) → Added Value of the Future Industrial Chain (+) → Regional Economic Growth (+) → Demand for Industry–University–Research Collaboration (+) → Mission-Oriented Innovation Consortia.

(4) Standardization–Industrial Upgrading Loop (R4)

Mission-Oriented Innovation Consortia → University Investment (+) → University Innovation Vitality (+) → University Technological Outcomes (+) → Technology Transfer (+) → Collaborative Innovation Efficiency (+) → Technical Standards Setting (+) → Product Competitive Advantage (+) → Added Value of the Future Industrial Chain (+) → Regional Economic Growth (+) → Demand for Industry–University–Research Collaboration (+) → Mission-Oriented Innovation Consortia.

(5) Technology Adaptation–Market Expansion Loop (R5)

Mission-Oriented Innovation Consortia → University Investment (+) → University Innovation Vitality (+) → Value Co-creation Intensity (+) → University Technological Outcomes (+) → Technology Transfer (+) → Technological Adaptability (+) → Technological Leadership (+) → Product Differentiation (+) → Industrial Market Demand (+) → Added Value of the Future Industrial Chain (+) → Regional Economic Growth (+) → Demand for Industry–University–Research Collaboration (+) → Mission-Oriented Innovation Consortia.

(6) Internal Friction Loop (B1)

Mission-Oriented Innovation Consortia → Free-riding Behavior (+) → Interest Conflict (+) → Collaborative Resistance (+) → Collaborative Innovation Efficiency (−) → Core Technology Breakthroughs (+) → Added Value of the Future Industrial Chain (+) → Regional Economic Growth (+) → Demand for Industry–University–Research Collaboration (+) → Mission-Oriented Innovation Consortia.

(7) Adaptive Resilience–Shock Mitigation Loop (B2)

Effective Technological Shock Impact → Adaptive Governance Response (+) → Mission-Oriented Innovation Consortia (+) → System Resilience (+) → Technological Adaptability (+) → Effective Technological Shock Impact (−).

3.3. Visualization of the Stock-Flow Diagram

The causal loop diagram can reveal the direction of relationships and feedback among system variables, but it is difficult to clearly distinguish state variables, rate variables, and auxiliary variables. To characterize the dynamic accumulation process through which mission-oriented innovation consortia empower future industry development, this study constructs a stock–flow diagram based on the causal relationship analysis, as shown in Figure 2.

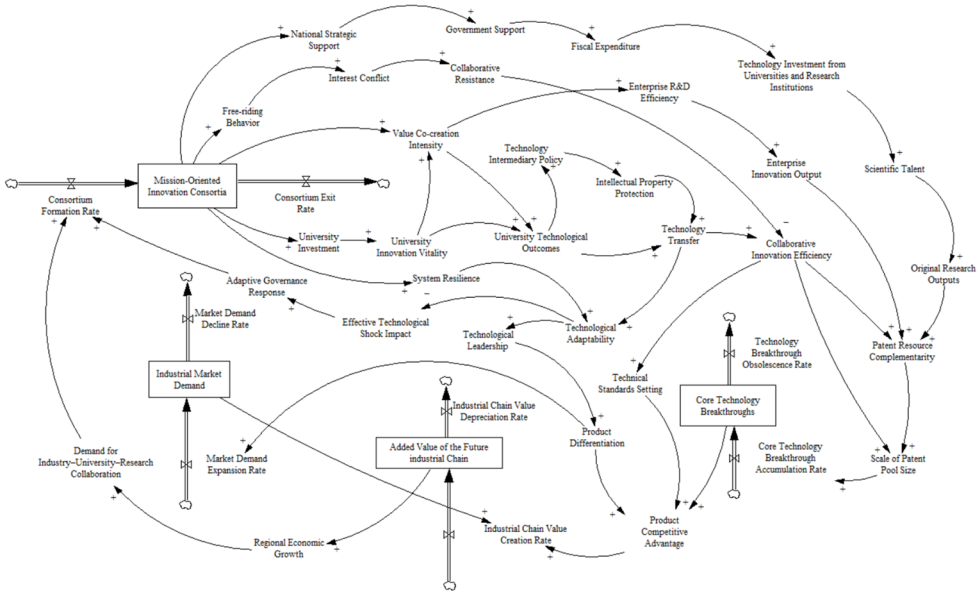


Figure 2. System dynamics stock-flow diagram. Note: To ensure the clarity of the diagram, the stock–flow diagram mainly presents the core state variables, major rate variables, and key feedback relationships. Some auxiliary variables are moderately aggregated in the diagram, but retained in the simulation equations to ensure the completeness of model calculation and the accuracy of dynamic behavior interpretation.

3.4. Multi-Source Parameter Identification

To improve the credibility of parameter settings and reduce the subjective bias that may arise from relying solely on expert judgment, this study identifies multi-source parameters by combining literature evidence, statistical data, large language model (LLM)-assisted text analysis, and expert consultation.

In the stage of model structure construction, the causal relationships and directions of influence among variables are mainly determined based on innovation ecosystem theory, dynamic capability theory, complex adaptive system theory, and literature on innovation consortia governance, so as to ensure that the model structure has a theoretical foundation. Second, for the initial values of key state variables, this study refers to the China Science and Technology Statistical Yearbook, the China Strategic Emerging Industries Development Report, and policy documents related to national-level innovation consortia, and conducts standardized processing based on the development characteristics of future industries to enhance the consistency between the model and the real-world context.

For qualitative behavioral parameters that are difficult to obtain directly from statistical data, such as collaborative resistance, free-riding behavior, interest conflict, and system resilience, this study adopts a method combining LLM-assisted text analysis and expert calibration, together with the analytic hierarchy process (AHP) and fuzzy comprehensive evaluation for parameter identification. Specifically, the LLM is mainly used to conduct semantic organization of policy texts, typical cases, and academic literature, and to summarize variable relationships. This forms a preliminary variable interpretation framework and provides a unified cognitive basis for expert evaluation. Subsequently, an evaluation panel consisting of 12 experts is formed, including five scholars in innovation management and industrial economics from universities, four researchers from research institutions, and three industry experts. The experts use the 1–9 scale to construct judgment matrices, and the weights are calculated using the AHP method. The consistency ratio (CR) of all judgment matrices is below 0.10, indicating good consistency in expert judgment.

In the fuzzy comprehensive evaluation process, the LLM is used only as an auxiliary tool for text information organization and initial evaluation semantics. The final mem-

bership matrix is determined by the expert panel after multiple rounds of revision and calibration, and parameter values are formed through fuzzy synthesis operations. This method combines, to some extent, the breadth of text mining with the domain depth of expert judgment, which helps improve the interpretability and consistency of qualitative parameter settings.

It should be noted that the purpose of constructing the system dynamics model in this study is not to make precise numerical predictions, but to reveal the internal feedback structure and dynamic evolutionary mechanism through which mission-oriented innovation consortia empower future industry development.

During model calibration, some key parameters are fine-tuned by combining the iterative calibration method of system dynamics, so that the model can reasonably characterize innovation input delays, the accumulation effect of technological breakthroughs, the constraint of collaborative resistance, and nonlinear growth in the process of industrial upgrading. Overall, the model can reveal, to a certain extent, how system factors such as national strategic support, value co-creation intensity, patent resource complementarity, collaborative innovation efficiency, technological adaptability, and internal friction jointly shape the dynamic evolution of future industries.

4. Simulation and Analysis

To characterize the long-term evolutionary trajectory through which mission-oriented innovation consortia empower future industry development, this study sets the total simulation period to 120 months, namely 10 years. The initial time is set as $T_0 = 0$, the end time as $T_{end} = 120$, and the time step is set on a monthly basis. The setting of this simulation period is mainly based on two considerations: the real-world policy cycle and the evolutionary patterns of future industries.

First, from the perspective of the policy cycle, future industry development is usually embedded in national medium- and long-term science and technology innovation plans and industrial strategic deployments. The formation, operation, and performance release of mission-oriented innovation consortia are not short-term processes, but involve multiple stages, including strategic task setting, resource allocation, collaborative R&D, achievement transformation, and industrial diffusion. A 10-year observation window can better cover organizational evolution and industry cultivation under the sustained influence of medium- and long-term science and technology innovation policies, and helps identify feedback reinforcement, delayed responses, and nonlinear changes at different stages of the system.

Second, from the perspective of technological innovation and industry cultivation, future industries generally involve long R&D cycles, high technological uncertainty, incomplete industrial chain support, and significant commercialization delays. From basic research investment to core technology breakthroughs, and then to the formation of stable added value of the future industrial chain and industrial market demand, a relatively long process of knowledge accumulation, technology verification, and market diffusion is usually required. Therefore, the 120-month simulation interval can relatively comprehensively present the full-process evolutionary features through which mission-oriented innovation consortia promote future industry development.

Considering that time delays have an important influence on system behavior in system dynamics models, this study further introduces structural delay mechanisms into the model to enhance its ability to represent real innovation processes. Specifically, two major delay parameters are set. First, the delay in R&D achievement transformation is set as $D_1 = 18$ months. Innovation activities in future industries involve knowledge accumulation and achievement transformation cycles. From national special project investment and fiscal support to the formation of transferable original research outputs by universities

and research institutions, multiple stages are usually required, including project initiation, research organization, technological problem solving, prototype development, and achievement verification. Therefore, this study sets the R&D achievement transformation delay to 18 months and embeds it into the formation process of core technology breakthroughs through the DELAY function, so as to reflect the objective lag in the transformation of science and technology input into core technology breakthroughs.

Second, the delay in technical standards and market diffusion is set as D_2 = 12 months. Core technology breakthroughs in future industries do not immediately translate into product competitive advantage and added value of the future industrial chain. Relevant technologies usually need to go through processes such as technical standards setting, industrial testing and verification, industrial chain adaptation, and market acceptance. Therefore, a 12-month delay in technical standards and market diffusion is introduced to characterize the time delay in the transformation of core technology breakthroughs into industrial value creation and market demand expansion. In the equation design, the above delay mechanisms are embedded into the formation process of core technology breakthroughs and the industrial chain value creation process through the DELAY function, so as to more realistically simulate the dynamic evolutionary patterns through which mission-oriented innovation consortia empower future industry development.

On this basis, the model is solved using Vensim PLE 7.3.5, and the simulation results are visualized using Python 3.10 (64-bit).

4.1. Baseline Analysis: Macro-Level Effects of Innovation Consortia in Empowering Future Industry Development

4.1.1. Innovation Consortia and Industrial Market Demand in Future Industries

Figure 3 shows the dynamic evolution of mission-oriented innovation consortia and industrial market demand under the baseline scenario. The results indicate that, during the 120-month simulation period, both variables generally show a continuous upward trend, but their growth rhythms and stage characteristics differ. Mission-oriented innovation consortia grow relatively slowly in the early stage of the simulation, then enter a rapid expansion stage around months 40–80, and gradually stabilize in the later stage. This suggests that, under the sustained influence of national strategic support, fiscal expenditure, and cross-actor coordination mechanisms, the development level of innovation consortia follows an evolutionary pattern from slow accumulation to accelerated expansion and then to relative stabilization.

By contrast, industrial market demand exhibits a certain delayed growth pattern. In the early stage of the simulation, industrial market demand grows relatively slowly. As the development level of innovation consortia increases, core technology breakthroughs gradually accumulate, and technical standards and product differentiation advantages are progressively formed, industrial market demand begins to rise more markedly in the middle and later stages, showing a relatively strong cumulative reinforcement trend. This indicates that the driving effect of mission-oriented innovation consortia on industrial market demand does not occur immediately, but gradually emerges after stages such as resource integration, technological R&D, achievement transformation, and market diffusion.

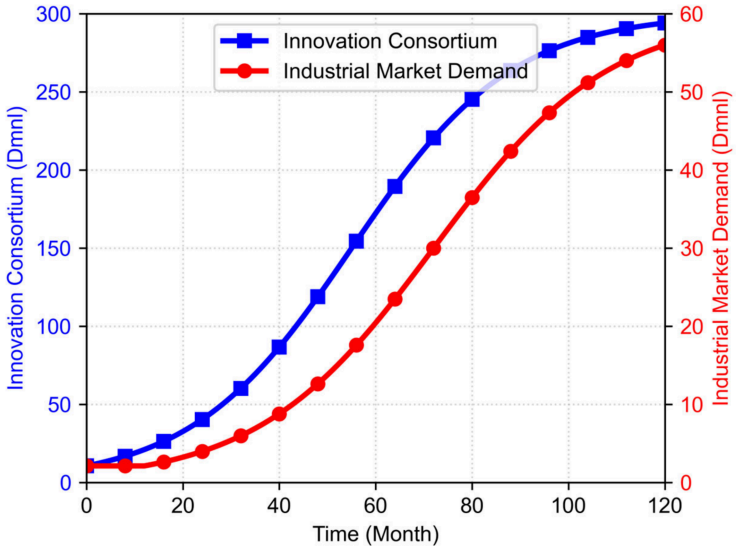


Figure 3. The dynamic trend of innovation consortium and industrial market demand. Note: The figure uses dual vertical axes to show the evolutionary trends of the two variables, and the variable values are relative values. Therefore, the numerical magnitudes of the two curves in the figure should not be directly compared. The focus is on revealing the dynamic association and staged lag relationship between the development of mission-oriented innovation consortia and industrial market demand. The same applies to the following figures.

In terms of the underlying mechanism, mission-oriented innovation consortia are guided by national strategic objectives and promote the formation of relatively stable collaborative innovation networks among enterprises, universities, research institutions, and technology intermediary agencies through government support, fiscal expenditure, and cross-actor resource integration. In this process, value co-creation intensity, patent resource complementarity, and technological adaptability continue to improve, thereby promoting core technology breakthroughs, product differentiation, and technical standards setting. As technological leadership and product application scenarios gradually expand, industrial market demand is continuously stimulated, which further reinforces demand for industry–university–research collaboration and the development level of mission-oriented innovation consortia.

Overall, the baseline simulation results show that mission-oriented innovation consortia can continuously empower future industry development through long-term collaborative innovation and technology transfer mechanisms, and can promote the transformation of industrial market demand from slow incubation to accelerated expansion.

4.1.2. Innovation Consortia and Core Technology Breakthroughs

Figure 4 reflects the dynamic relationship between mission-oriented innovation consortia and core technology breakthroughs. Overall, as the development level of mission-oriented innovation consortia continues to improve, the level of core technology breakthroughs shows a sustained upward trend, with a relatively clear cumulative growth pattern in the middle and later stages. This is because mission-oriented innovation consortia can effectively integrate heterogeneous innovation resources from enterprises, universities, and research institutions under the joint influence of national strategic support and fiscal expenditure, thereby promoting the accumulation of original research outputs and cross-actor knowledge flows.

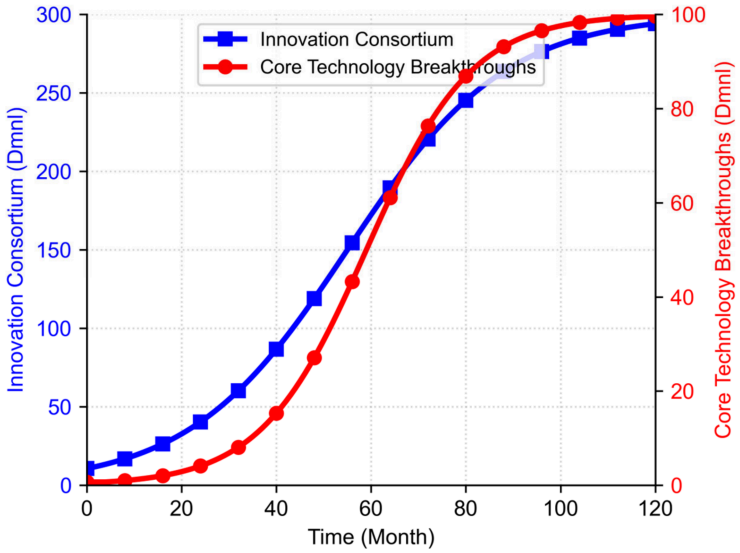


Figure 4. The dynamic trend of innovation consortium and core technology breakthroughs.

Further, the deepening of value co-creation intensity, the improvement of patent resource complementarity, and the expansion of the scale of patent pool size help improve collaborative innovation efficiency and promote knowledge spillover, technological integration, and key technology problem solving. Core technology breakthroughs are not the direct result of innovation input by a single actor, but the outcome of the long-term operation of multi-actor collaborative innovation networks and the continuous accumulation of resources. As technology transfer continues to advance, patent resources accumulate, and collaborative innovation efficiency gradually improves, mission-oriented innovation consortia can form a positive feedback mechanism involving knowledge sharing, technological integration, and innovation diffusion, thereby continuously enhancing the level of core technology breakthroughs.

4.1.3. Innovation Consortia and Added Value of the Future Industrial Chain

Figure 5 shows the dynamic evolution trend of mission-oriented innovation consortia and the added value of the future industrial chain. The simulation results indicate that, during the 120-month simulation period, the two variables generally show a same-direction growth relationship. However, the increase in the added value of the future industrial chain lags behind the development level of mission-oriented innovation consortia to some extent. Specifically, in the early stage of the simulation, due to time delays in technological R&D, achievement transformation, technical standards setting, and industrial application diffusion, the added value of the future industrial chain grows relatively slowly. As the development level of innovation consortia continues to improve, collaborative innovation efficiency increases, core technology breakthroughs gradually accumulate, and technical standards and product competitive advantage begin to take shape, the added value of the future industrial chain enters a faster growth stage in the middle and later stages.

From the perspective of system dynamics, the increase in the added value of the future industrial chain is not the result of a single factor, but rather the joint outcome of multiple mechanisms, including national strategic support, value co-creation intensity, patent resource complementarity, core technology breakthroughs, technical standards setting, and product differentiation. On the one hand, core technology breakthroughs provide the technological foundation for upgrading the future industrial chain. On the other hand, the formation of technical standards and the improvement of product competitive advantage further promote the diffusion of innovation outcomes into industrialization

processes, and enhance the overall value creation capability of the industrial chain through the expansion of industrial market demand. As the internal coordination mechanisms of mission-oriented innovation consortia gradually mature, the reinforcing feedback effects within the system continue to strengthen, ultimately promoting a sustained increase in the added value of the future industrial chain.

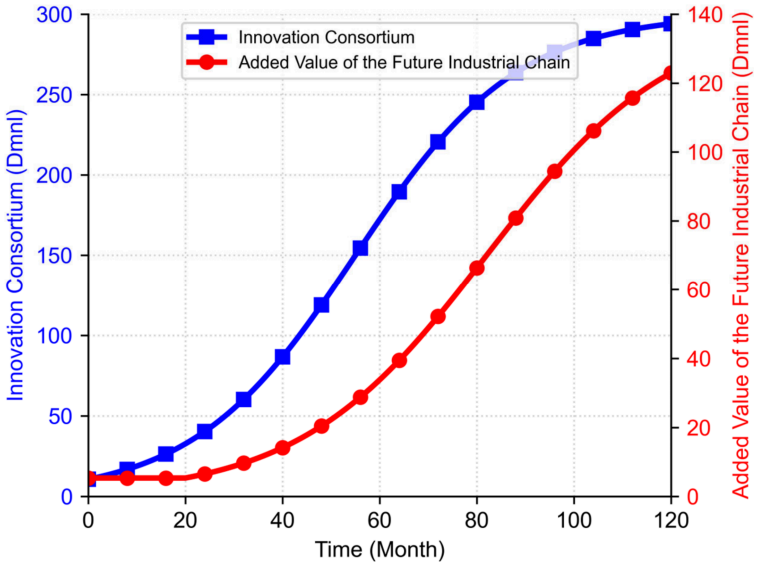


Figure 5. The dynamic trend of innovation consortium and added value of the future industrial chain.

4.2. Mechanism Analysis: Mechanisms Through Which Innovation Consortia Empower Future Industry Development

4.2.1. Value Co-Creation

Figures 6 and 7 show the dynamic evolution of value co-creation intensity during the development of innovation consortia. As shown in Figure 6, value co-creation intensity generally exhibits a continuous upward trend during the simulation period, with clear stage-based evolutionary characteristics. In the early stage of the simulation, enterprises, universities, and research institutions are still in the process of resource alignment and the establishment of collaborative relationships. Cross-actor trust, knowledge-sharing mechanisms, and coordination rules have not yet been fully formed, so value co-creation intensity grows relatively slowly. As the development level of mission-oriented innovation consortia continues to improve, government support, fiscal expenditure, and organizational coordination mechanisms gradually take effect. Enterprise innovation willingness, university innovation vitality, and collaborative innovation efficiency continue to increase, and value co-creation intensity enters a stage of rapid growth. In the later stage of the simulation, as the collaborative structure of the consortia gradually matures, the growth rate of value co-creation intensity slows down and gradually stabilizes.

In terms of the underlying mechanism, value co-creation is an important mechanism through which mission-oriented innovation consortia empower future industry development. On the one hand, mission-oriented innovation consortia reduce the cost of knowledge exchange among enterprises, universities, and research institutions through organized coordination, thereby promoting the integration of heterogeneous knowledge resources. On the other hand, an increase in value co-creation intensity can further enhance enterprise R&D efficiency and enterprise innovation output, and promote patent resource complementarity and core technology breakthroughs. Thus, the value co-creation mechanism forms an important positive transmission path between innovation consortia and future industry development.

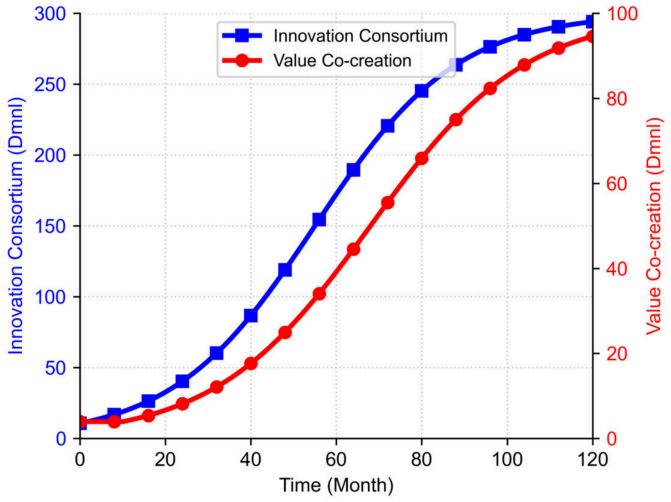
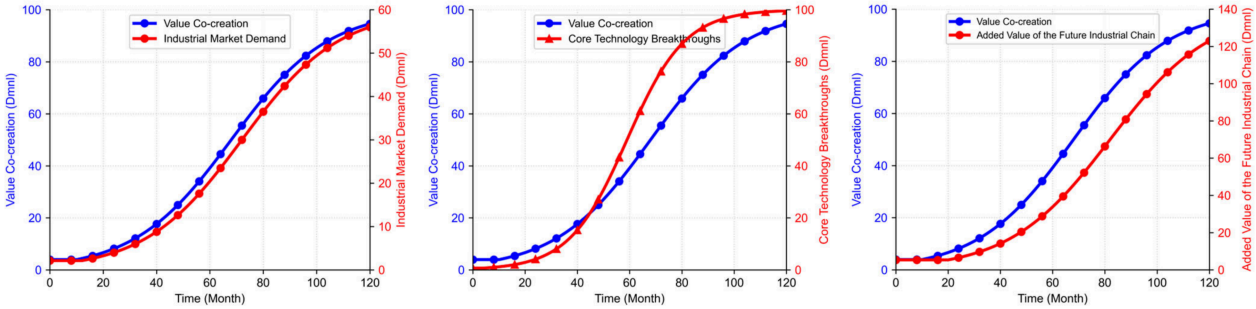


Figure 6. The dynamic trend of innovation consortium and value co-creation intensity.



(a) The co-evolution trend of value co-creation and industrial market demand

(b) The co-evolution trend of value co-creation and core technology breakthroughs

(c) The co-evolution trend of value co-creation and added value of the future industrial chain

Figure 7. The dynamic trend of value co-creation intensity and future industry development.

Figure 7a–c further show the dynamic relationships between value co-creation intensity and industrial market demand, core technology breakthroughs, and added value of the future industrial chain. The simulation results indicate that, as value co-creation intensity continues to increase, all three variables related to future industry development show sustained upward trends, suggesting that the value co-creation mechanism has a strong positive driving effect on future industry development. Specifically, the increase in value co-creation intensity helps strengthen knowledge sharing, resource integration, and collaborative problem-solving among innovation actors. By improving collaborative innovation efficiency and patent resource complementarity, it further promotes core technology breakthroughs, market demand expansion, and the increase in added value of the future industrial chain.

From the perspective of the mechanism, value co-creation does not directly affect only a single outcome variable, but exerts systemic influence through multiple feedback paths. On the one hand, value co-creation can improve enterprise R&D efficiency and enterprise innovation output, thereby enhancing patent resource complementarity and core technology breakthroughs. On the other hand, value co-creation can also promote university innovation vitality and technology achievement transformation, further supporting technological adaptability, product differentiation, and market demand expansion. As these mechanisms continue to accumulate, the added value of the future industrial chain shows a more pronounced growth pattern in the middle and later stages. Therefore, value co-creation is an important transmission mechanism through which mission-oriented innovation consortia empower future industry development.

4.2.2. Patent Resource Complementarity

Figures 8 and 9 show the dynamic evolution of patent resource complementarity. As shown in Figure 8, with the deepening development of mission-oriented innovation consortia, patent resource complementarity generally shows a continuous upward trend, with clear stage-based characteristics. In the early stage of the simulation, patent resources, technological paths, and knowledge bases among different innovation actors are still in the process of identification and matching, so patent resource complementarity improves relatively slowly. In the middle stage, as collaborative R&D, patent combinations, achievement sharing, and intellectual property coordination mechanisms within the consortia gradually improve, heterogeneous knowledge resources among enterprises, universities, and research institutions become more fully integrated, leading to a marked increase in patent resource complementarity. In the later stage, as the structure of patent resource integration gradually matures, its growth rate slows down and tends to stabilize.

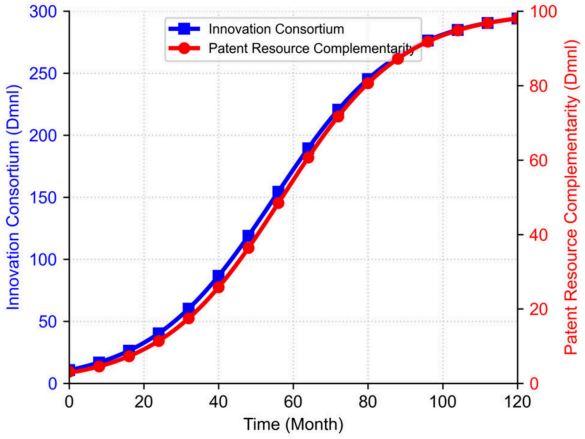
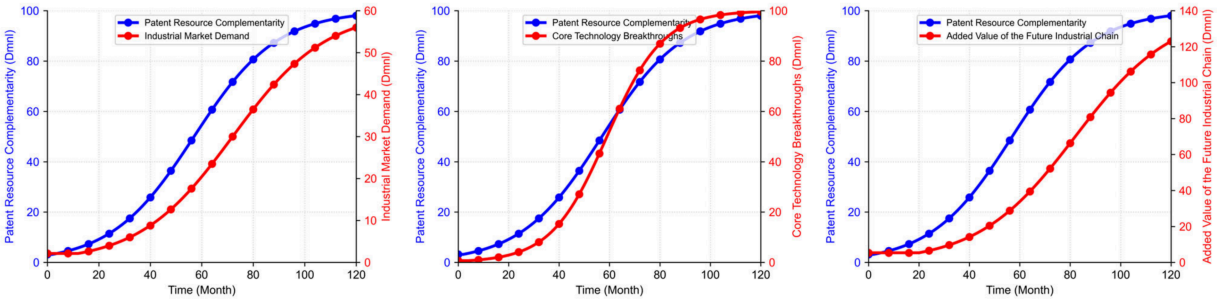


Figure 8. The dynamic trend of innovation consortia and patent resource complementarity.



(a) The co-evolution trend of patent resource complementarity and industrial market demand

(b) The co-evolution trend of patent resource complementarity and core technology breakthroughs

(c) The co-evolution trend of patent resource complementarity and added value of the future industrial chain

Figure 9. The dynamic trend of patent resource complementarity and future industry development.

In terms of the underlying mechanism, mission-oriented innovation consortia can promote the transformation of dispersed patent resources into systematic technological combinations through cross-actor knowledge integration, joint R&D, and the construction of patent pools. The improvement of patent resource complementarity not only helps reduce duplicated R&D and technological barriers, but also expands the scale of patent pool size and strengthens the resource base for core technology breakthroughs. Therefore, patent resource complementarity is an important mechanism through which mission-oriented innovation consortia promote core technology breakthroughs and future industry development.

Figure 9a–c further show that patent resource complementarity has clear same-direction evolutionary relationships with industrial market demand, core technology

breakthroughs, and added value of the future industrial chain. Among them, the dynamic changes in patent resource complementarity and core technology breakthroughs are more synchronized, indicating that patent resource complementarity provides important support for the formation of core technology breakthroughs. In terms of the mechanism, patent resource complementarity can promote the integration of heterogeneous knowledge among different innovation actors, reduce duplicated R&D costs, improve the efficiency of knowledge recombination, and increase the possibility of transforming original research outputs into industrial applications.

Within mission-oriented innovation consortia, the patents, technological paths, and R&D experience held by enterprises, universities, and research institutions are highly complementary. Through joint R&D, patent combinations, and patent pool construction, dispersed technological resources can be integrated into more systematic technological capabilities, thereby providing sustained support for core technology breakthroughs. Furthermore, achieving breakthroughs in core technologies is an important objective of mission-oriented innovation consortia. By strengthening knowledge integration, technological combination, and collaborative innovation, patent resource complementarity can not only promote core technology breakthroughs, but also further drive the expansion of industrial market demand and the increase in added value of the future industrial chain. Therefore, patent resource complementarity constitutes a key foundational mechanism through which mission-oriented innovation consortia empower future industry development.

4.2.3. Technological Adaptability

Figures 10 and 11 show the dynamic role of technological adaptability in the process through which innovation consortia empower future industry development. The simulation results indicate that, as the development level of mission-oriented innovation consortia continues to improve, technological adaptability generally shows a sustained upward trend, with certain lagged and stage-based characteristics. In the early stage of the simulation, technological collaboration among enterprises, universities, and research institutions is still being established, and technology transfer, knowledge absorption, and application scenario adaptation remain insufficient. As a result, technological adaptability increases relatively slowly. In the middle stage, as collaborative R&D and technology transfer within the consortia continue to advance, enterprises' capabilities for absorbing, digesting, and re-innovating new technologies gradually improve, and technological adaptability enters a stage of rapid growth. In the later stage, as technology absorption mechanisms and organizational learning mechanisms gradually mature, the growth rate of technological adaptability slows down and gradually stabilizes.

In terms of the underlying mechanism, technological adaptability is an important mediating variable through which mission-oriented innovation consortia transform technological achievements into market applications and industrial value. A higher level of technological adaptability can enhance the ability of enterprises and industrial chain actors to absorb, apply, and adapt frontier technologies to specific scenarios, and further promote technological leadership, product differentiation, and market demand expansion. Therefore, the technological adaptability mechanism plays a key bridging role in the process through which innovation consortia empower future industry development.

Figure 11a–c further show the dynamic relationships between technological adaptability and industrial market demand, core technology breakthroughs, and added value of the future industrial chain. The simulation results indicate that, as technological adaptability continues to improve, all three outcome variables generally show sustained growth trends, suggesting that technological adaptability plays an important transmission role in the process through which mission-oriented innovation consortia empower future industry

development. Among them, technological adaptability shows a relatively direct same-direction relationship with industrial market demand, indicating that improvements in technological adaptability help enhance the responsiveness of future industry products and services to market environments, application scenarios, and changes in technological paradigms, thereby promoting market demand expansion.

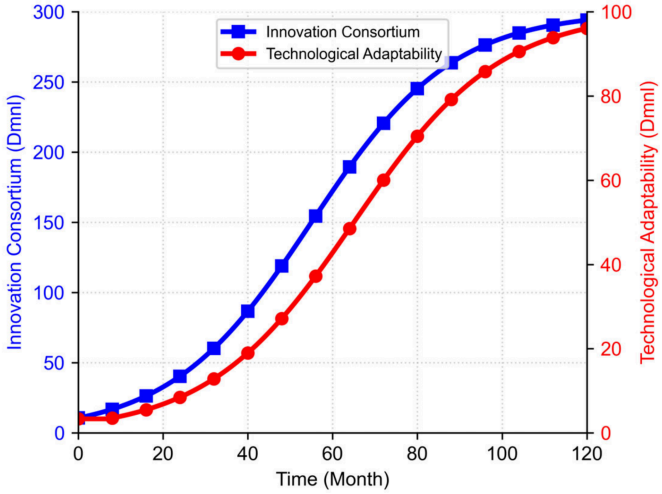
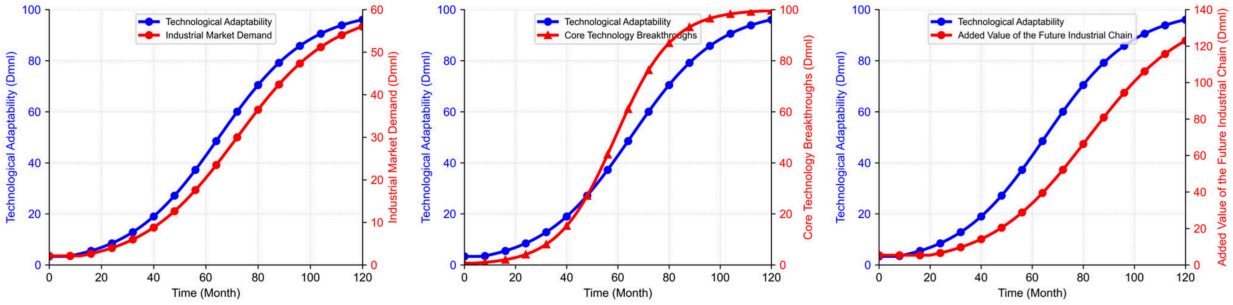


Figure 10. The dynamic trend of innovation consortia and technological adaptability.



(a) The co-evolution trend of technological adaptability and industrial market demand

(b) The co-evolution trend of technological adaptability and core technology breakthroughs

(c) The co-evolution trend of technological adaptability and added value of the future industrial chain

Figure 11. The dynamic trend of technological adaptability and future industry development.

From the perspective of the mechanism, technological adaptability mainly operates through two paths. On the one hand, improvements in technological adaptability can enhance the ability of enterprises and industrial chain actors to absorb, digest, and re-innovate frontier technologies, and promote industrial market demand expansion through technological leadership and product differentiation. On the other hand, technological adaptability can also promote technology transfer and collaborative innovation efficiency, indirectly supporting core technology breakthroughs and the increase in added value of the future industrial chain. For future industries, technological change is rapid and technological trajectories are highly uncertain. Technology supply alone is insufficient to form sustained competitive advantage. Only when enterprises and industrial chain actors can quickly adapt to and effectively apply new technologies can technological achievements be smoothly industrialized and transformed into market value. Therefore, technological adaptability is not only an important bridge connecting technological innovation and market diffusion, but also a key transmission mechanism through which mission-oriented innovation consortia realize industrial empowerment. By enhancing technology absorption capability, product differentiation capability, and market responsiveness, technological

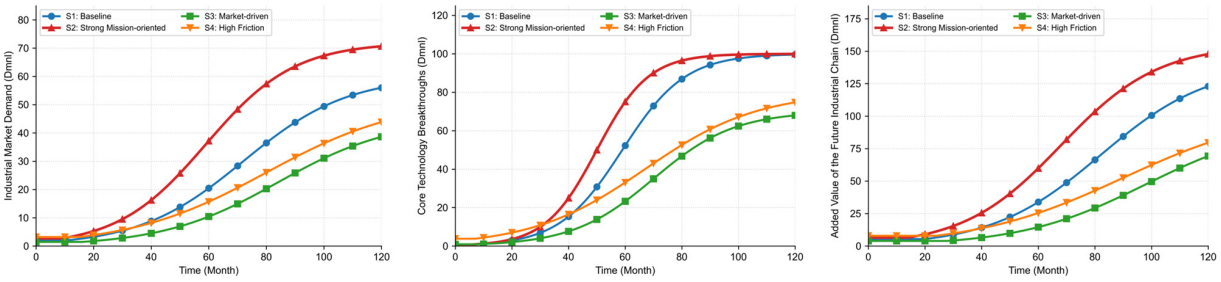
adaptability promotes the transition of future industries from the stage of technological accumulation to the stage of market expansion and value creation.

The above baseline simulation and key mechanism analysis show that value co-creation intensity, patent resource complementarity, and technological adaptability jointly constitute the important internal mechanisms through which mission-oriented innovation consortia empower future industries. These simulation results are consistent with the basic views of triple helix theory, innovation ecosystem theory, and dynamic capability theory, indicating that the model can effectively characterize the internal logic through which mission-oriented innovation consortia promote the evolution of future industries. On this basis, this study further conducts policy simulation under multiple governance scenarios.

4.3. Policy Simulation Analysis Under Multiple Governance Scenarios

4.3.1. Scenario Design

To further examine the policy conditions and governance effects through which mission-oriented innovation consortia empower future industry development, this study constructs policy simulation scenarios under different governance modes based on the baseline scenario. The scenario design focuses on three key variables: national strategic support, collaborative innovation efficiency, and collaborative resistance (see Table 2), so as to examine the influence of different governance modes on the evolutionary path of future industries. This study selects industrial market demand, core technology breakthroughs, and added value of the future industrial chain as the core output variables of the system, and conducts a 120-month dynamic simulation under different governance scenarios. By comparing the differences in system evolutionary trajectories across scenarios, this study further analyzes the mechanisms and policy effects of national strategic support, collaborative innovation efficiency, and collaborative resistance on future industry development. The simulation results are shown in Figure 12a–c.



(a) The evolution trend of industrial market demand under multiple governance scenarios

(b) The evolution trend of core technology breakthroughs under multiple governance scenarios

(c) The evolution trend of added value of the future industrial chain under multiple governance scenarios

Figure 12. The evolutionary trends of future industry development under multiple governance scenarios.

Table 2. Scenario design.

Scenario	National Strategic Support	Collaborative Innovation Efficiency	Collaborative Resistance	Scenario Meaning
S1 baseline scenario	baseline value	baseline value	baseline value	current governance level
S2 strong mission-oriented scenario	+30%	+20%	−20%	strengthened national strategy and optimized collaborative governance
S3 market-driven scenario	−30%	baseline value	+20%	weakened policy support and market-dominated mechanisms
S4 high-friction governance scenario	+20%	−20%	+30%	increased resource input but ineffective internal governance

4.3.2. Strong Mission-Oriented Scenario

The strong mission-oriented scenario increases national strategic support by 30% and collaborative innovation efficiency by 20% based on the baseline scenario, while moderately reducing collaborative resistance by 20%. This scenario is used to simulate a policy environment in which the government continues to increase special investment, improve innovation coordination mechanisms, and strengthen organizational governance.

The simulation results show that, under the strong mission-oriented scenario, industrial market demand, core technology breakthroughs, and added value of the future industrial chain all exhibit faster growth trends, and their overall levels are clearly higher than those under other scenarios. In particular, the growth inflection point of core technology breakthroughs appears earlier, and the growth rate of added value of the future industrial chain accelerates markedly. This indicates that, under the joint effect of national strategic support and efficient coordination mechanisms, mission-oriented innovation consortia can complete resource integration, knowledge flows, and technological problem solving more quickly, thereby strengthening the reinforcing feedback effects within the system.

In terms of the underlying mechanism, sustained input of national strategic resources not only enhances the capacity for innovation resource allocation, but also improves the willingness of multiple actors to collaborate by stabilizing expectations and reducing uncertainty. At the same time, the improvement of collaborative innovation efficiency accelerates knowledge sharing, technology transfer, and achievement transformation, while the decline in collaborative resistance reduces the inhibitory effects of interest conflict, free-riding behavior, and coordination costs on system operation. Therefore, the strong mission-oriented scenario can more fully release the enabling effect of innovation consortia on future industry development.

4.3.3. Market-Driven Scenario

The market-driven scenario reduces national strategic support by 30% and increases collaborative resistance by 20% based on the baseline scenario. This scenario is used to simulate a governance mode in which innovation actors mainly rely on market mechanisms for cooperation, while government strategic guidance and organizational coordination are relatively weakened.

The simulation results show that, compared with the baseline scenario, the expansion speed of industrial market demand under the market-driven scenario slows down significantly, while the growth levels of core technology breakthroughs and added value of the future industrial chain are also relatively lower. The time at which the system enters the rapid growth stage is also delayed. This suggests that future industries are characterized by strong technological uncertainty, long-term investment needs, and high risks. Relying solely on market mechanisms makes it difficult to effectively overcome resource constraints, coordination costs, and transformation delays in the process of frontier technology breakthroughs.

Under the condition of insufficient sustained strategic support, the resource integration capacity, collaborative innovation capability, and cross-actor technology transfer capability of innovation consortia are weakened to some extent. Especially in terms of core technology breakthroughs and the increase in added value of the future industrial chain, the market-driven scenario fails to form sufficiently strong mechanisms for sustained investment and collaborative problem solving, thereby reducing the long-term enabling effect of innovation consortia on future industry development.

4.3.4. High-Friction Governance Scenario

The high-friction governance scenario increases national strategic support by 20% based on the baseline scenario, while reducing collaborative innovation efficiency by 20% and increasing collaborative resistance by 30%. This scenario is used to simulate situations such as insufficient organizational coordination, intensified interest conflict, increased free-riding behavior, and governance failure.

The simulation results indicate that the system still maintains a certain growth trend under the high-friction governance scenario, suggesting that external strategic support can provide resource guarantees and directional guidance for future industry development to some extent. However, compared with the baseline scenario and the strong mission-oriented scenario, the growth rates of industrial market demand, core technology breakthroughs, and added value of the future industrial chain all slow down significantly under the high-friction governance scenario. This indicates that internal friction weakens the actual transformation effect of policy resource input.

Further comparison shows that the high-friction governance scenario still outperforms the market-driven scenario in some outcome variables, indicating that national strategic support has a certain bottom-line supporting effect. However, due to the decline in collaborative innovation efficiency and the increase in collaborative resistance, strategic support cannot be fully transformed into core technology breakthroughs and industrial value improvement. This result suggests that future industry development depends not only on external policy input, but also on the effective operation of internal coordination mechanisms within innovation consortia. Without stable value co-creation mechanisms, interest coordination mechanisms, and efficient collaborative networks, simply increasing resource input cannot fully release innovation potential and may even lead to reduced resource allocation efficiency and innovation performance losses.

4.3.5. Scenario Comparison and Implications

The simulation results across different scenarios show that the evolutionary paths of future industry development differ significantly under different governance scenarios. The strong mission-oriented scenario exhibits the optimal development path, indicating that national strategic support, improved collaborative innovation efficiency, and reduced collaborative resistance can jointly strengthen the enabling effect of mission-oriented innovation consortia. In contrast, the market-driven scenario and the high-friction governance scenario weaken system growth capacity to varying degrees, as reflected in slower expansion of industrial market demand, insufficient accumulation of core technology breakthroughs, and delayed increase in added value of the future industrial chain.

Further comparison of the dynamic evolutionary processes across scenarios shows that national strategic support can provide stable resource guarantees and directional guidance for future industry development. However, its effect is not automatically realized; rather, it needs to be transformed through efficient coordination mechanisms and a low-friction governance structure. When collaborative innovation efficiency declines or collaborative resistance rises, the marginal transformation effect of policy resources is weakened, and the system growth path deviates from that under the strong mission-oriented scenario.

Therefore, the governance focus of mission-oriented innovation consortia lies not only in increasing innovation resource input, but also in improving collaborative governance capacity through institutional design and organizational coordination. It is necessary to reduce cooperation costs among actors and improve mechanisms for benefit sharing, risk sharing, and intellectual property coordination, so as to form a sustained and stable innovation feedback network. For future industries, the coordinated promotion of national strategic support and optimized collaborative governance is an important guarantee

for achieving core technology breakthroughs, industrial market demand expansion, and industrial value upgrading.

4.4. Model Validity Explanation

In system dynamics research, model validity is an important prerequisite for ensuring the credibility of simulation results. Given that future industries are highly frontier-oriented and uncertain, long-cycle historical data are currently insufficient for point-by-point fitting and validation of the model. Therefore, following the general validation logic of system dynamics research, this study explains model validity from four aspects: structural validity, behavioral consistency, parameter robustness, and extreme condition testing.

4.4.1. Structural Validity

Structural validity mainly examines whether the model variables, causal relationships, and feedback structures are consistent with real-world logic and theoretical foundations. This study takes mission-oriented innovation consortia as the research object, and the system covers core actors such as leading enterprises, universities and research institutions, government departments, technology intermediary agencies, and upstream and downstream enterprises in the industrial chain. The selection of variables and the construction of causal relationships are mainly based on triple helix theory, innovation ecosystem theory, dynamic capability theory, and complex adaptive system theory, and are further adjusted according to the practical construction of national innovation consortia.

In terms of variable setting, the model introduces key variables such as national strategic support, value co-creation intensity, patent resource complementarity, collaborative innovation efficiency, technological adaptability, collaborative resistance, system resilience, and effective technological shock impact, so as to capture the governance characteristics that distinguish mission-oriented innovation consortia from ordinary market-oriented R&D alliances and traditional industry–university–research alliances. In terms of feedback structure, the model characterizes reinforcing loops such as the strategic mission–technology breakthrough loop, value co-creation–enterprise innovation loop, knowledge transfer–collaborative innovation loop, standardization–industrial upgrading loop, and technology adaptation–market expansion loop, as well as balancing mechanisms such as internal friction and shock mitigation. Overall, the model structure can reasonably reflect the dynamic relationships among resource allocation, knowledge flows, technological breakthroughs, market expansion, and industrial value creation in the development of future industries, and thus has certain theoretical rationality and practical explanatory power.

4.4.2. Behavioral Consistency

Behavioral consistency testing mainly examines whether the model operation results conform to real industrial evolutionary patterns and theoretical expectations. The baseline simulation results show that industrial market demand, core technology breakthroughs, and added value of the future industrial chain generally exhibit dynamic features of slow growth in the early stage, accelerated improvement in the middle stage, and gradual stabilization in the later stage. This evolutionary trend is broadly consistent with the process of knowledge accumulation, technology verification, achievement transformation, and market diffusion usually experienced by future industries.

In addition, the R&D achievement transformation delay, the technical standards and market diffusion delay, the cumulative effect of technological breakthroughs, and the nonlinear growth brought about by collaborative innovation shown by the model are also consistent with the patterns of long-term investment, high risk, path dependence, and phased diffusion in real innovation activities. The multi-scenario simulation results further show that national strategic support and optimized collaborative governance

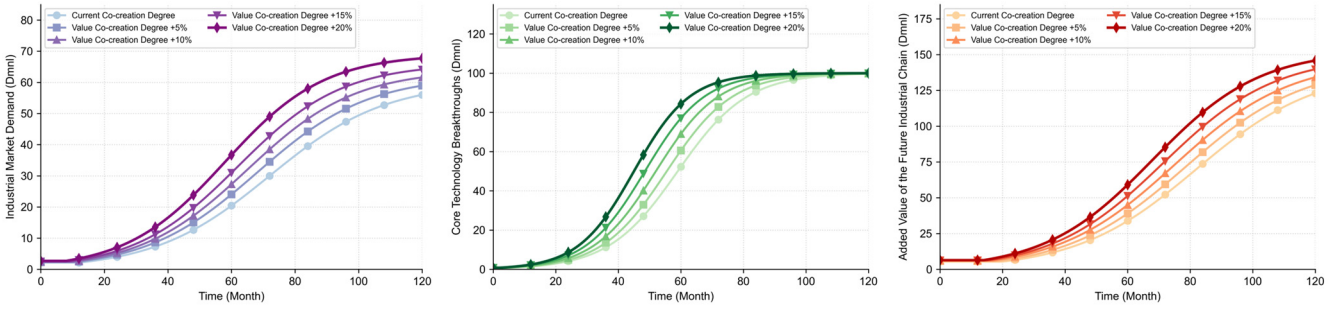
can significantly improve the development level of future industries, while increased collaborative resistance weakens the enabling effect of innovation consortia. These results are consistent with theoretical expectations and real-world experience, indicating that the model can effectively characterize the main behavioral features through which mission-oriented innovation consortia empower future industry development.

4.4.3. Parameter Sensitivity Analysis

Sensitivity analysis examines changes in the core output variables of the system by adjusting key parameter values while keeping other variables and parameters within the system boundary relatively unchanged, so as to judge the response degree of model behavior to changes in key factors. Based on the model structure and key mechanism analysis above, this study selects value co-creation intensity, patent resource complementarity, and collaborative innovation efficiency as the main parameters for sensitivity analysis. Industrial market demand, core technology breakthroughs, and added value of the future industrial chain are selected as the core output variables of the system, so as to examine the influence of changes in key mechanism variables on future industry evolution.

(1) Sensitivity analysis of the impact of value co-creation intensity on future industry development

This study increases the value co-creation intensity parameter by 5%, 10%, 15%, and 20%, respectively, and compares the results with the baseline scenario. The simulation results are shown in Figure 13. The results indicate that, as the value co-creation intensity parameter continues to increase, industrial market demand, core technology breakthroughs, and added value of the future industrial chain all improve to varying degrees. This suggests that the value co-creation mechanism has a strong positive effect on future industry development.



(a) The evolution of industrial market demand under the change of value co-creation

(b) The evolution of core technology breakthroughs under the change of value co-creation

(c) The evolution of added value of the future industrial chain under the change of value co-creation

Figure 13. The sensitivity analysis of value co-creation intensity.

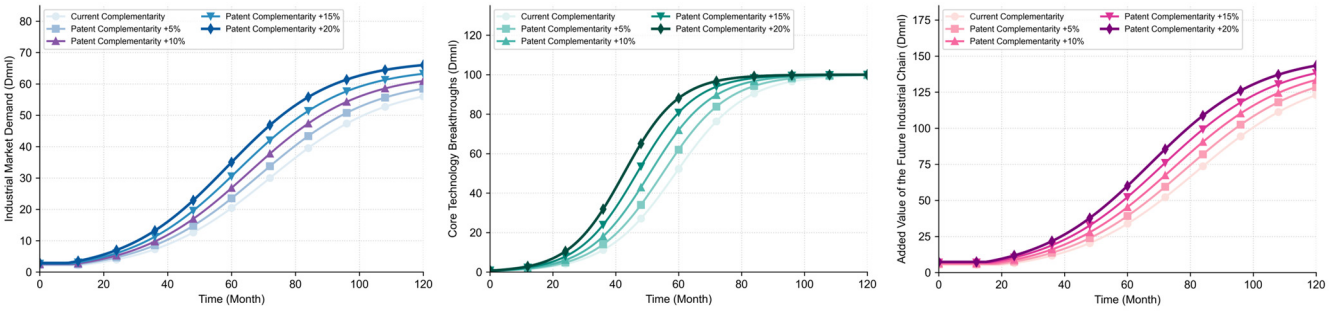
Specifically, after value co-creation intensity increases, the industrial market demand curve shifts upward overall, indicating that cross-actor collaborative innovation can enhance the market responsiveness of future industry products and services. The growth inflection point of the core technology breakthroughs curve appears earlier, suggesting that value co-creation helps promote knowledge sharing, joint R&D, and patent resource complementarity, thereby improving the efficiency of core technology problem solving. The added value of the future industrial chain also increases accordingly, reflecting that the value co-creation mechanism can further enhance industrial value creation through technological breakthroughs, achievement transformation, and market diffusion.

In terms of the underlying mechanism, the value co-creation mechanism strengthens knowledge sharing and resource integration among enterprises, universities, and research institutions, improves collaborative innovation efficiency, and promotes the complementary allocation of patent resources. On this basis, innovation actors can carry out joint

R&D and technological problem solving more efficiently, accelerate the process of core technology breakthroughs and achievement transformation, further drive the expansion of industrial market demand through technological leadership and product differentiation, and continuously promote the increase in added value of the future industrial chain.

(2) Sensitivity analysis of the impact of patent resource complementarity on future industry development

This study further increases the patent resource complementarity parameter by 5%, 10%, 15%, and 20%, respectively, and compares the results with the baseline scenario. The simulation results are shown in Figure 14. The results show that, as patent resource complementarity continues to increase, industrial market demand, core technology breakthroughs, and added value of the future industrial chain all improve to varying degrees. This indicates that the patent resource complementarity mechanism has a strong positive effect on future industry development.



(a) The evolution of industrial market demand under the change of patent complementarity

(b) The evolution of core technology breakthroughs under the change of patent complementarity

(c) The evolution of added value of the future industrial chain under the change of patent complementarity

Figure 14. The sensitivity analysis of patent resource complementarity.

Specifically, after patent resource complementarity improves, the growth inflection point of the core technology breakthroughs curve appears earlier, and the growth rate also accelerates. This suggests that patent resource complementarity can provide a more sufficient knowledge base and technological support for core technology problem solving. At the same time, industrial market demand and added value of the future industrial chain also increase, indicating that patent resource complementarity not only affects the process of technological breakthroughs, but can also further promote market demand expansion and industrial value creation through technological combinations, achievement transformation, and product application expansion.

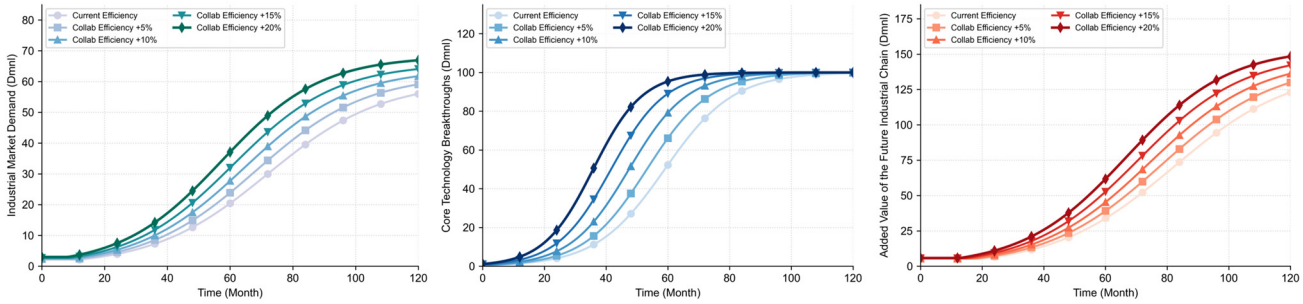
In terms of the underlying mechanism, the development of mission-oriented innovation consortia is accompanied by cross-actor integration of patent resources and the expansion of the scale of patent pool size. Heterogeneous patent resources held by enterprises, universities, and research institutions are complementarily allocated through joint R&D, patent combinations, and intellectual property coordination mechanisms. This helps reduce duplicated R&D costs, alleviate technological discontinuities between upstream and downstream actors in the industrial chain, and improve knowledge recombination efficiency. Compared with homogeneous patent accumulation, heterogeneous patent complementarity is more conducive to forming targeted technological combinations around national strategic needs and core technology breakthrough tasks, thereby enhancing original technological breakthrough capability.

Furthermore, patent resource complementarity can promote cross-domain integration among technological modules, expand the application scenarios of future industry products and services, and drive the growth of added value of the future industrial chain through core technology breakthroughs and improved product competitive advantage.

Therefore, patent resource complementarity is not only an important support for core technology breakthroughs, but also a foundational mechanism through which mission-oriented innovation consortia promote future industry market expansion and industrial value improvement.

(3) Sensitivity analysis of the impact of collaborative innovation efficiency on future industry development

This study increases the collaborative innovation efficiency parameter by 5%, 10%, 15%, and 20%, respectively, and compares the results with the baseline scenario. The simulation results are shown in Figure 15. The results indicate that, as the collaborative innovation efficiency parameter continues to increase, industrial market demand, core technology breakthroughs, and added value of the future industrial chain all improve to varying degrees. This suggests that collaborative innovation efficiency is a key mechanism variable affecting how mission-oriented innovation consortia empower future industry development.



(a) The evolution of industrial market demand under the change of collaborative innovation efficiency

(b) The evolution of core technology breakthroughs under the change of collaborative innovation efficiency

(c) The evolution of added value of the future industrial chain under the change of collaborative innovation efficiency

Figure 15. The sensitivity analysis of collaborative innovation efficiency.

Specifically, after collaborative innovation efficiency improves, the growth inflection point of the core technology breakthroughs curve appears significantly earlier, and the growth rate in the middle stage accelerates. This indicates that high-level collaborative innovation can effectively promote the flow and recombination of knowledge, technology, and innovation resources among enterprises, universities, research institutions, and technology intermediary agencies, thereby improving the efficiency of core technology problem solving. At the same time, industrial market demand and added value of the future industrial chain also rise, indicating that collaborative innovation efficiency not only affects the process of technological breakthroughs, but also further drives future industry development through achievement transformation, the formation of product competitive advantage, and market diffusion.

In terms of the underlying mechanism, the higher the collaborative innovation efficiency, the more effectively innovation consortia can reduce coordination costs and knowledge transfer barriers in cross-actor cooperation, improve patent resource complementarity and the efficiency of innovation achievement transformation, and further strengthen core technology breakthrough capability. As key technologies continue to accumulate, the technological leadership and product competitive advantage of future industries are enhanced, which in turn promotes market demand expansion and industrial value improvement.

In summary, when value co-creation intensity, collaborative innovation efficiency, and patent resource complementarity are increased respectively, industrial market demand, core technology breakthroughs, and added value of the future industrial chain all improve to varying degrees. This indicates that the three mechanisms are important supporting factors through which mission-oriented innovation consortia empower fu-

ture industry development. Among them, value co-creation intensity reflects the depth and breadth of collaborative problem solving carried out by different innovation actors around national strategic tasks; collaborative innovation efficiency reflects the efficiency of knowledge, technology, and innovation resources in inter-organizational flow, integration, and transformation; and patent resource complementarity reflects the integration capability of heterogeneous technological resources and innovation achievements. These three mechanisms correspond respectively to the construction of collaborative relationships, the improvement of network operation efficiency, and the complementary allocation of knowledge resources in the innovation ecosystem, jointly constituting the key support system for future industry innovation and development.

The sensitivity analysis results further show that, through multiple tests of changes in key parameters, the evolutionary trends of the main state variables of the model remain consistent within a reasonable fluctuation range, with no abnormal oscillation or system divergence. Parameter changes mainly affect the growth rate and growth magnitude of variables, but do not change the overall evolutionary direction of the system. This indicates that the model has good behavioral stability and parameter robustness. Overall, future industry development exhibits strong system dependence. Compared with simply increasing innovation resource input, improving inter-actor collaborative relationships, enhancing collaborative innovation efficiency, and optimizing the operation mechanism of cross-actor innovation networks have a more sustained driving effect on long-term system evolution. This means that the policy focus of mission-oriented innovation consortia should not only be on R&D funding and innovation resource supply, but should also attach importance to the construction of value co-creation mechanisms, the enhancement of collaborative governance capacity, and the optimization of cross-actor innovation networks. In particular, it is necessary to strengthen resource coordination and core technology joint problem-solving capabilities under the guidance of national strategic tasks, so as to fully leverage the institutional advantages of mission-oriented innovation consortia in promoting future industry development.

4.4.4. Extreme Condition Testing

Extreme condition testing is used to examine whether the model still conforms to basic logic under boundary conditions. This study sets a loss of national strategic support scenario and an optimal synergy scenario, and compares them with the baseline scenario. The results are shown in Figure 16.

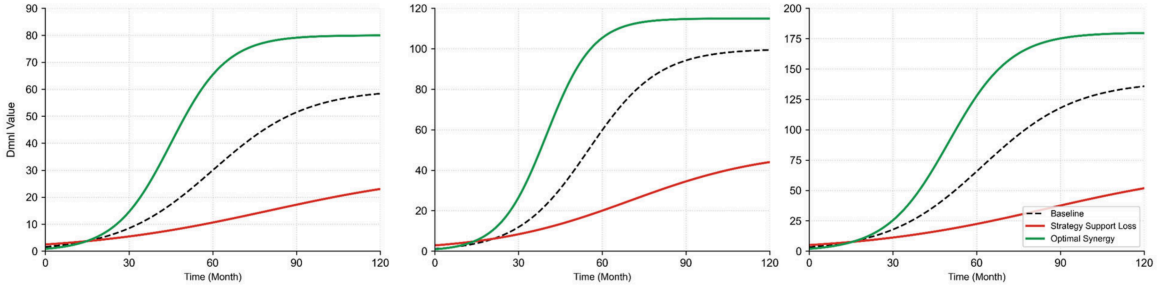


Figure 16. The evolutionary trend of future industry development under extreme conditions.

Under the loss of national strategic support scenario, the level of national strategic support is reduced to a low level. The simulation results show that the growth rates of core technology breakthroughs, industrial market demand, and added value of the future industrial chain all decline significantly, and the system finds it difficult to enter the rapid growth stage. This indicates that, under the background of high uncertainty and high investment

demand in future industries, the development of mission-oriented innovation consortia is highly dependent on sustained strategic support, policy guidance, and innovation resource input. Without national strategic support, collaborative innovation activities within the system cannot be fully carried out, and both core technology breakthroughs and industrial value creation are significantly constrained.

Under the optimal synergy scenario, collaborative resistance is set at a low level, while collaborative innovation efficiency within the system is set at a high level. The simulation results show that core technology breakthroughs, industrial market demand, and added value of the future industrial chain all exhibit faster growth trends, and are clearly higher than those in the baseline scenario. This indicates that, when interest conflict, free-riding behavior, and organizational coordination costs are effectively controlled, knowledge flows, technology transfer, and resource integration within innovation consortia can be significantly improved, thereby strengthening the reinforcing feedback process of core technology breakthroughs and industrial value creation.

Overall, the results of extreme condition testing are consistent with the basic theoretical expectations regarding how mission-oriented innovation consortia empower future industry development. The loss of national strategic support weakens the growth momentum of the system, while optimized collaborative governance enhances the system's reinforcing feedback effects. These results indicate that the model maintains good directional consistency and behavioral rationality under extreme conditions, and has a certain degree of structural robustness.

5. Case Study

5.1. Case Selection

Next-generation artificial intelligence and large model ecosystems, as well as humanoid robots, are both typical future intelligent industries. They share common characteristics such as strong technological uncertainty, high requirements for cross-actor collaboration, significant dependence on application scenario diffusion, and time delays in industrial chain value creation. Considering the research context and case comparability, this study selects the multimodal artificial intelligence industrial consortium in Wuhan, China, and the national-local co-built embodied intelligent robot innovation center in Beijing, China, as cases (see Table 3). Both cases are characterized by national strategic guidance, multi-actor co-construction, and application-scenario orientation. They provide empirical references for the major feedback mechanisms in the system dynamics model from two perspectives: platform ecosystem-based collaborative innovation and software–hardware integrated joint problem solving, thereby further illustrating the real-world adaptability of the model structure.

Table 3. Typical cases of future intelligent industries.

Future Industry Scenario	Typical Practice Carrier	Specific Real-World Case
Next-generation artificial intelligence and large model ecosystem	large model open platforms, industry large model joint innovation ecosystems, and artificial intelligence open innovation platforms	multimodal artificial intelligence industrial consortium (Wuhan, China)
Humanoid robots	humanoid robot innovation consortia, robot innovation centers, and key component–whole-machine collaborative platforms	national-local co-built embodied intelligent robot innovation center (Beijing, China)

5.2. Next-Generation Artificial Intelligence and Large Model Ecosystem

Next-generation artificial intelligence and large model ecosystems are among the future intelligent industries with prominent platform-based and networked characteristics. Their innovation process depends on coordinated interactions among algorithmic models, computing power infrastructure, data resources, industry knowledge, and application scenarios. Large model ecosystems usually follow a cyclic process of model capability improvement, application scenario expansion, user feedback accumulation, model retraining and optimization, and the continued entry of ecosystem actors. This process is highly consistent with the value co-creation, collaborative innovation efficiency, and technological adaptability mechanisms in the model.

The multimodal artificial intelligence industrial consortium was established in December 2021, with the participation of the Institute of Automation of the Chinese Academy of Sciences, Wuhan Artificial Intelligence Research Institute, and other organizations. It aims to integrate resources from industry, universities, research institutions, and users, and to promote the development of the multimodal artificial intelligence industry and the industrialization of general artificial intelligence. The consortium brings together multiple types of actors, including computing power providers, vertical industry enterprises, universities, and research institutions, reflecting the mission-oriented collaborative innovation characteristics of pursuing domestic, controllable, and industrially applicable general multimodal large models.

Taking the "Zidong Taichu" large model ecosystem as an example, Wuhan Artificial Intelligence Research Institute is responsible for the iteration of the general large model foundation, university research teams provide algorithmic support such as multimodal alignment and lightweight inference, industry enterprises open application scenarios such as medical device management, rail transit operation and maintenance, and industrial welding, while computing centers provide domestic intelligent computing resources. Through shared industry datasets, joint R&D, and co-built industry fine-tuning laboratories, multiple actors promote the continuous iteration of model capabilities and make progress in multimodal reasoning, industrial scenario adaptation, and industry applications. This process corresponds to variables such as Value Co-creation Intensity, Collaborative Innovation Efficiency, Enterprise Innovation Output, and Patent Resource Complementarity in the SD model, reflecting the reinforcing feedback mechanism of multi-actor knowledge sharing, improved collaborative innovation efficiency, and core technology iteration.

From the perspective of technological adaptability, the industrial value of large model technologies does not depend solely on the parameter scale of foundation models, but on whether they can adapt to diverse application scenarios such as manufacturing, healthcare, transportation, education, and public administration. The consortium carries out vertical fine-tuning and application adaptation for differentiated scenarios such as industrial welding, medical device management, rail transit operation and maintenance, and low-altitude inspection, and gradually forms scenario-based applications such as new media content retrieval, intelligent cockpits, digital humans, and sign language teaching and examination systems. This process corresponds to variables such as Technological Adaptability, Product Differentiation, and Industrial Market Demand in the model. It shows that the development of large model ecosystems is not the result of technological supply by a single enterprise, but a systemic evolutionary process jointly shaped by platform enterprises, research institutions, industry application actors, and scenario data feedback. This is broadly consistent with the logic of the model, in which value co-creation, collaborative innovation efficiency, and technological adaptability jointly drive future industry development.

5.3. Humanoid Robots

Humanoid robots are a future intelligent industry characterized by a high degree of software–hardware integration, a long technological chain, and significant industrialization delays. Their development depends not only on artificial intelligence algorithms and embodied intelligence models, but also on multiple technological modules such as reducers, servo motors, sensors, motion control, materials and processes, and whole-machine integration. Since a single enterprise usually cannot cover all technological links independently, the humanoid robot industry highly depends on mission-oriented innovation consortia to systematically integrate multi-actor technological resources.

The national-local co-built embodied intelligent robot innovation center was jointly established by industry actors such as UBTECH, Jingcheng Machinery Electric, Xiaomi Robotics, and E-Town Robotics. It focuses on full-chain key technologies for humanoid robots, including the "brain", "cerebellum", and "limbs", and covers component R&D, whole-machine integration, embodied algorithms, and scenario verification. This reflects organizational characteristics such as strategic mission guidance, multi-actor collaborative problem solving, and industrial chain integrated innovation.

From the perspective of core technology breakthroughs, the humanoid robot industry faces key technological bottlenecks such as high-precision motion control, dexterous manipulation, environmental perception, multimodal interaction, low-cost mass production, and adaptation to complex scenarios. In the practice of this innovation center, universities and research institutions mainly undertake basic research tasks related to embodied intelligence algorithms and multimodal perception; core component enterprises participate in key hardware problem solving such as high-precision servos and lightweight joints; whole-machine enterprises are responsible for system integration and mass production process optimization; and application scenario actors provide testing, verification, and iterative feedback. By jointly building carriers such as the general robot mother platform "Tiangong", the consortium promotes the formation of a collaborative problem-solving chain among basic algorithms, core hardware, and whole-machine integration. This process corresponds to the reinforcing feedback logic of strategic mission input, cross-actor knowledge transfer, and core technology breakthroughs in the model.

From the perspective of patent resource complementarity and industrial chain value creation, humanoid robots involve multiple technological fields, including mechanical structures, control algorithms, sensing systems, artificial intelligence models, and application scenarios. Patents and technological resources held by different actors are highly complementary. Resource integration through innovation consortia helps reduce duplicated R&D and technological discontinuities, enhances Patent Resource Complementarity and Scale of Patent Pool Size, and further supports the accumulation of Core Technology Breakthroughs. At the same time, the transition of humanoid robots from laboratory prototypes to large-scale applications requires technology verification, cost reduction, standard setting, and scenario adaptation, reflecting clear delays in R&D achievement transformation and market diffusion.

In addition, multi-actor collaboration in the humanoid robot industry may also face problems such as benefit allocation, intellectual property ownership, technological route divergence, and standards competition. Without effective governance mechanisms, collaborative resistance may increase and innovation efficiency may decline. This is consistent with the internal friction mechanism in the model, indicating that collaborative governance capacity is an important factor affecting the industrialization process of humanoid robots. Overall, this case provides real-world references for the model from the perspectives of core technology breakthroughs, patent resource complementarity, collaborative innovation efficiency, industrial value creation, and internal friction governance.

5.4. Model Consistency Assessment and Case Implications

The two cases show that both next-generation artificial intelligence and large model ecosystems, and humanoid robots, embody the basic characteristics of mission-oriented innovation consortia. Specifically, they form cross-actor collaborative innovation networks around key technological bottlenecks and strategic application scenarios in future intelligent industries, involving platform enterprises, chain-leading enterprises, universities and research institutions, industrial chain enterprises, and application scenario actors. This indicates that the model and its core variables have a real-world foundation. At the same time, the real operation of the two cases can be mapped respectively to key mechanisms in the model, including value co-creation, knowledge transfer, technological adaptability, patent resource complementarity, collaborative innovation efficiency, and core technology breakthroughs, suggesting that the main causal loops set in the model have a certain degree of real-world adaptability.

From the perspective of dynamic evolution, the large model ecosystem shows platform feedback and application diffusion effects, while humanoid robots exhibit long-term accumulation constrained by core technology breakthroughs and industrialization delays. These patterns are broadly consistent with the simulation results of this study. The case analysis also indicates that the development of future intelligent industries cannot rely entirely on technological supply by a single enterprise or spontaneous diffusion through market mechanisms. Instead, it requires the joint action of national strategic support, platform-based enterprise organization, university research support, industrial chain collaboration, and application scenario traction. Overall, the two cases provide supplementary empirical support for the structural assumptions and dynamic behavioral features of the system dynamics model, indicating that the model can effectively characterize the main mechanisms through which mission-oriented innovation consortia drive the development of future intelligent industries.

6. Conclusions

6.1. Main Conclusions

Based on the system dynamics method, this study constructs a dynamic simulation model of how mission-oriented innovation consortia empower future industry development. By establishing the stock–flow diagram, causal loops, and equation settings, this study reveals the endogenous feedback structure through which innovation consortia drive the evolution of future industries. The results show that mission-oriented innovation consortia exert a sustained and stable positive effect on future industry development. However, this effect does not emerge immediately. Instead, it is gradually released over time through mechanisms such as value co-creation intensity, patent resource complementarity, technology transfer, standardization diffusion, and technological adaptability.

Specifically, in the early stage of system evolution, the process is mainly characterized by the expansion of innovation consortia and the accumulation of knowledge resources. In the middle stage, under the joint effects of core technology breakthroughs, technical standards setting, and industrial market demand expansion, the system enters a stage of accelerated growth. In the later stage, as constraints such as demand saturation, technological depreciation, and factor cost increase become stronger, the growth rate gradually slows down. Overall, mission-oriented innovation consortia form an endogenous dynamic system that drives the continuous evolution of future industries through multi-actor collaboration and cross-level resource integration. Their mechanism of action shows significant features of delay, nonlinearity, and reinforcing feedback.

6.2. Discussion

6.2.1. Theoretical Contributions

The theoretical contributions of this study are mainly reflected in two aspects. First, this study revises the implicit assumption in existing research that collaborative innovation input and future industry performance can be understood as a simple linear relationship. The revised model shows that the evolution of future industries is not directly driven by a single input variable, but is jointly shaped by multiple feedback loops, structural delays, and governance frictions. Especially in the mission-oriented context, there are clear stage-dominant relationships among policy support, knowledge transformation, and market diffusion. Therefore, future industry performance is more appropriately understood as a dynamic process of feedback reinforcement, delayed release, and constrained convergence.

Second, this study further extends the analytical framework of the dual constraint of "strategic orientation–governance friction" in research on mission-oriented innovation consortia. Compared with traditional market-oriented alliances, mission-oriented innovation consortia do not take profit maximization as their sole objective, but are embedded in national strategic tasks, fiscal risk-sharing mechanisms, and collaborative governance mechanisms. Therefore, national strategic support can, to some extent, resist technological uncertainty and market volatility. However, if collaborative resistance continues to rise and collaborative innovation efficiency declines, the system may still experience slower growth, delayed value creation, or even local instability. This finding suggests that national strategic support cannot automatically be transformed into industrial upgrading outcomes. Only when organizational governance is effective, technology transfer is smooth, and standardization diffusion mechanisms are sound can policy resources be truly transformed into long-term momentum for the evolution of future industries.

6.2.2. Limitations and Future Paths

Although this study improves the robustness and explanatory power of the model through multi-source parameter calibration, sensitivity analysis, and extreme scenario testing, several limitations remain due to the complexity of future industry systems. First, this study has not fully characterized the endogenous evolution of macro policy cycles, international supply chain shocks, and fluctuations in industrial factor prices. Future studies may introduce policy pulses, supply chain disruption, and stochastic disturbance modules outside the system boundary, so as to enhance the model's ability to capture complex environmental shocks.

Second, this study still uses an aggregated modeling approach to represent heterogeneous actors such as universities, enterprises, research institutions, and technology intermediary agencies, and does not explicitly simulate strategic interactions, contractual learning, and evolutionary games among different actors. Future research can further build a hybrid simulation framework combining system dynamics and agent-based modeling, embedding cooperation decisions, benefit allocation, and opportunistic behavior at the micro-actor level into the macro feedback structure, thereby improving the behavioral realism and policy operability of the model.

6.3. Managerial Implications

As strategic emerging industries increasingly require dynamic adaptability, single-actor innovation models have become insufficient to support the complex evolutionary needs of future industries. Based on the findings of this study, the following management implications are proposed.

First, the policy design of mission-oriented innovation consortia should not emphasize only the scale of funding input, but should pay greater attention to the coordinated

allocation among resource input, collaborative governance, and technology diffusion capability. For future industries, simply increasing government support or fiscal expenditure is not sufficient to ensure that the system enters a high-growth trajectory. It is also necessary to simultaneously improve collaborative innovation efficiency and effectively reduce collaborative resistance.

Second, the governance of two key types of delay should be emphasized. One is the delay in R&D achievement transformation, and the other is the delay in standardization and market diffusion. Governments and chain-leading enterprises should shorten the transmission chain from original research outputs to industrial value creation through pilot-scale platforms, patent pools, standard coordination mechanisms, and the opening of application scenarios.

Third, the construction of value co-creation mechanisms should be regarded as a key aspect of consortium governance. Through demand traction, benefit sharing, process evaluation, and knowledge-sharing rules, it is necessary to enhance university innovation vitality and innovation willingness, thereby improving patent resource complementarity and technology transfer efficiency.

Fourth, a dynamic governance mode oriented toward shock scenarios should be established. Uncertain variables such as technological shocks and factor cost increase should be incorporated into regular monitoring, and system resilience should be enhanced through phased policy repair, rapid standard coordination, and risk compensation mechanisms. For future industries, truly effective governance is not a one-time injection of resources, but a sustained policy orchestration oriented toward long-term missions, cross-actor collaboration, and adaptability to external shocks.

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