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Innovative ecosystems for green agriculture: a four-Helix + intermediary model for rural development

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Introduction: Green agriculture innovation requires synergistic collaboration among government, academia, industry, farmers, and intermediaries to drive sustainable rural development.

Methods: We constructed a "Four-Helix + Intermediary" model and evaluated it using a harmonious development (HD) coefficient based on multi-omics field data from the soapberry industry in Queshan County.

Results: The overall synergy coefficient among actors reached 0.6821 ("relative synergy"), with high coordination in government–enterprise investment and farmer satisfaction, but weaker university–enterprise collaboration and farmer labor input.

Conclusion: Institutionalizing intermediary roles and targeted policy mechanisms can enhance collaborative innovation, offering a replicable framework for green agriculture and rural revitalization.

KEYWORDS

cooperative innovation, green agriculture, innovation ecosystem, four-Helix + intermediary institutions, rural revitalization, collaborative innovation

1 Introduction

The modernization of agriculture in China has been steadily advancing, with annual grain production exceeding 650 billion kilograms since the initiation of reforms and opening up. Only through strengthening agriculture can a nation achieve strength (Xi, 2023). The steady growth in grain production has laid a solid foundation for adjusting agricultural structures, freeing rural productive forces, and continuously increasing farmers' incomes. However, the widespread adoption of agricultural management models has escalated resource constraints (Yu, 2018). Agricultural production faces severe challenges, such as environmental pollution and resource scarcity (Chen, 2002). Innovative-driven development necessitates a new perspective, and agriculture is no exception. China's agriculture urgently needs to return to a green and natural approach, promoting the imperative shift toward green agricultural development (Jin and Han, 2020).

Innovation-driven development is key to achieving the goals of green agriculture development. Technological innovation can assist in more effectively utilizing resources, reducing environmental pollution, and enhancing agricultural production efficiency. For instance, agricultural green digital technologies can systematically monitor and analyze agricultural production activities, the environmental conditions of production sites, and the entire agricultural product production, processing, and sales process to achieve the greening, intelligence, and efficiency of agricultural industrial activities (Zhang, 2022). Moreover, technological innovation can also aid in the development of more green agricultural products, transforming the current situation of oversupply of common agricultural products and scarcity of green, high-quality, branded agricultural products, thereby increasing the supply of premium, safe, and distinctive agricultural products, and shifting the focus from primarily meeting quantity demands to emphasizing quality requirements (Xu, 2022).

Since 2004, the central government has issued 21 consecutive "Number 1 documents," signaling high prioritization of agricultural, rural, and farmer issues. Many promulgated documents and policies emphasize the green transformation of agriculture, the prioritized development of agriculture and rural areas, and the comprehensive advancement of rural revitalization (Jin et al., 2020). These intensive policy implementations demonstrate that the governance of agricultural ecological environments and the development of green transformation have been elevated to national strategic levels (Zhang, 2020). Therefore, research on green agricultural development holds strong real urgency and practical application value.

Green agriculture development is currently a prominent academic focus. Since the concept of sustainable development was introduced in 1987, scholars have conducted in-depth research on green development (Yu, 2016; Yang and Wei, 2022), primarily focusing on the analysis of the connotations of green agricultural development (Luo, 2017; Tu and Gan, 2019; Li and Gong, 2020), level measurement (Huang et al., 2017; Wei et al., 2018; Li et al., 2022), and differentiation analysis (Jin, 2019; Liu et al., 2020; Zhang, 2020). Regarding cooperative research, ecologists initially proposed the concept of collaborative innovation (Ehrlich and Raven, 1964; Pang et al., 2015). In 1994, Noragerd first applied the concept of collaborative innovation to social, cultural, and ecological economics. Subsequently, scholars began to study the evolutionary process of interdisciplinary cooperation from the perspective of collaborative innovation (Moore, 1996; Mckelvey, 1997), with research focusing on three aspects: connotation definitions (Wang et al., 2016), model analysis (Lee et al., 2012; Martin et al., 2014), and factor analysis (Xu et al., 2003; Cui and Su, 2012). Of course, some scholars have also researched the concept (Wu and Gu, 2012), model (Wang et al., 2008), and motivation (Zhou et al., 2013) of school-enterprise cooperation.

Currently, the study of green agriculture from a cooperative perspective primarily focuses on green agriculture development policies (Chu, 2021), green agriculture development and industrial agglomeration (Xue et al., 2019), green industry and green finance (He et al., 2020), and the development of urban–rural green agriculture industry chains (Xiong and Zhang, 2021), among other aspects. Despite notable progress in the field, three key research gaps remain. First, the theoretical framework for collaborative innovation in green agriculture is still underdeveloped, especially within the context of China's rural revitalization strategy. Second, existing applications of the quadruple helix model are largely confined to industrial contexts, with limited attention to the role of farmers as independent actors in agricultural innovation. Third, the coordinating functions of intermediary institutions, such as cooperatives and agricultural service centers, in linking government, academia, industry, and farmers have been insufficiently explored (Huipeng, 2020).

This study advances theoretical, behavioral, and policy-level innovations to address these gaps. Theoretically, the "civil society" element in the quadruple helix is redefined as "farmers," forming a government–university-industry–farmer innovation system. Intermediary institutions are systematically incorporated to establish a five-actor ("quadruple + intermediary") collaborative ecosystem tailored to agriculture. The study integrates the Technology Acceptance Model (TAM) and diffusion of innovation theory at the behavioral level to frame the drivers of farmers' green technology adoption. Policy-wise, we propose actionable mechanisms such as tiered fiscal support and demand-driven technology translation to enhance institutional support and implementation effectiveness.

Based on this framework, the study takes the Zaojiao (Gleditsia) industry in Queshan County as a case, aiming to construct and validate a collaborative innovation model for green agricultural development (Figure 1). The paper is structured as follows: Section 2 outlines the theoretical foundations and the construction of the quadruple helix model; Section 3 introduces the coordination evaluation method and indicator system; Section 4 presents empirical findings based on the case study; Section 5 reconstructs and extends the model under the rural revitalization strategy; and Section 6 concludes with policy recommendations.

2 Theoretical logic

2.1 Study on the impact of the development of the Chinese soapberry industry in Que Mountain County on rural revitalization

Located in the southern part of Henan Province, Que Mountain County has become an ideal location for soapberry cultivation due to

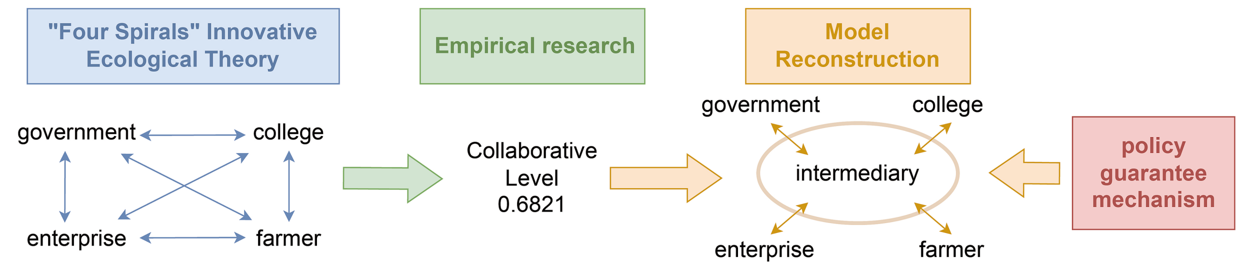

FIGURE 1
Research route of "Four Spirals" model for green agriculture and rural revitalization.

its unique geographical and climatic conditions. The long-standing cultivation of soapberries has positively contributed to the local ecological environment and has also demonstrated significant application value in the economic and medical fields (Ma, 2015). This study focuses on the innovative practices of Henan Hanyi Daily Chemical Technology Co., Ltd. in utilizing soapberry resources and explores its specific impacts on rural economic revitalization and the increase of farmers' income.

According to the investigation (The information on soapberry trees, thorns, kernels, leaves, and seeds in this section is derived from promotional materials provided by Mr. Li, General Manager of Henan Hanyi Daily Chemical Technology Co., Ltd., retrieved on March 29, 2022), soapberries are rich in flavonoids and are commonly used in treating cancers such as breast and lung cancer, being recognized as important medicinal herbs. Their fruits serve as natural raw materials in pharmaceuticals, health products, cosmetics, and cleaning supplies. The kernels contain various vitamins with notable health and cosmetic benefits. Soapberry powder is used in wettable pesticide formulations for its excellent dispersing, wetting, and suspending properties. Leaves, with a protein content of about 20%, can be utilized as woody feed or industrial cleaning agents. Seeds are high in plant gum (approximately 68%), with their polysaccharides widely applied as industrial materials. Additionally, soapnuts can be processed into eco-friendly car wash and household detergents. Overall, the soapberry industry has broad development prospects, supporting rural industrial restructuring, increasing farmer incomes, and contributing to poverty alleviation.

Considering data availability and case authenticity, we selected Henan Hanyi Daily Chemical Technology Co., Ltd. as the primary data source. The company, established through local cooperatives and family farms, is a key target of coordinated support between universities and local government. This case is highly representative in the field of green agriculture. First, Queshan County, a national-level poverty-stricken area, has developed an integrated soapberry industry chain, from cultivation to processing and sales, serving as a model for green rural transformation. Second, soapberry, with medicinal, nutritional, and cleaning value, embodies the ecological and economic attributes of green agriculture. Third, Hanyi acts as a local leading enterprise that integrates universities, government, farmers, and intermediaries into a "quadruple helix + intermediary" collaborative innovation system. This aligns well with the theoretical model proposed in this study and provides a replicable example of how collaborative innovation can support rural revitalization through sustainable agriculture.

The company focuses on the R&D, production, and sale of soapberry-based detergents, dishwashing liquids, and hand sanitizers. Supported by rural revitalization and poverty alleviation policies, it received strong governmental backing in its early stages. In addition to generating economic benefits, it helped lift 316 households out of poverty through procurement, land transfers, and employment, earning broad social recognition [Data from internal records of Henan Hanyi Daily Chemical Technology Co., Ltd., released by the Queshan County Poverty Alleviation Office, January 15, 2021]. Employing a "three-three" innovation model, the company promotes collaborative innovation to drive product development and integrate primary, secondary, and tertiary industries (Table 1). This case illustrates how green agriculture can enhance rural revitalization and increase farmer incomes. Henan Hanyi's success highlights the soapberry industry's potential as a driver of rural economic growth through innovation and policy support.

TABLE 1 Achievements of soap horn industry development models.

Connotation of development model	Achievement
Product innovation with three interlocking links	Developed five series of saponin cleaning products, natural saponin stock solution Dish-washing liquid, laundry detergent, soapy rice three gel face and other domestic exclusive products
	The revenue from soap horn cleaning products reached 8.6 million yuan in 2019, and the revenue exceeded 13 million yuan in 2020.
	Developed a soap rice series of nutritional foods, with a revenue of 3.9 million yuan in 2020.
Innovative model of tripartite collaboration	The school enterprise cooperation has become a supporting unit for the provincial engineering technology research center of natural plant cleaning technology in Henan Province.
	Establish an advanced natural plant cleaning industry technology research and development base.
	Obtained a county (city) innovation guidance plan project in Henan Province, with a funding of 500,000 yuan.
Development model of integrating three industries	Establish a standardized planting base for three varieties, covering an area of 900 acres, while also establishing a seedling breeding base, covering an area of 104 acres.
	Holding a standardized soap horn planting base of 2,160 acres and a breeding experiment base of 510 acres.
	A soap horn cleaning solution production factory consisting of extraction workshop, cleaning solution production workshop, and packaging workshop, with laboratories and inspection and analysis rooms.
	Preliminary construction of an ecological planting and product experience ecological sightseeing park for soap horn.

The data in the table was sourced from the poverty alleviation summary report of Henan Hanyi Daily Chemical Technology Co., Ltd.

2.2 Theoretical foundation of quadruple helix and construction of quadruple helix innovative ecological model

The Quadruple Helix structure is an innovative extension built upon the Triple Helix model, considering public authority's socialization and intermediary organizations' role within the "university-industry-government" Triple Helix framework (Yang and Wu, 2012). This new model forms a Quadruple Helix innovation ecosystem involving academia, industry, government, and civil society (Huang et al., 2016). In this context, "academia" refers to academic community organizations such as higher education institutions and research institutions (Huang and Wang, 2018), "industry" pertains to the production, research, and technology transfer activities conducted by universities, "government" is positioned toward service provision and guidance, while "civil society" mainly comprises third-party organizations, social groups, and forces (Huang and Wang, 2018). The core driving force of the Quadruple Helix is the research community, serving as the intersection of academia, industry, government, and civil society. The realization of the research community depends largely on factors such as disciplinary development, team growth, innovation drive, and implementation platforms (Huang and Wang, 2018). In contrast to the knowledge economy focus of the Triple Helix model, the Quadruple Helix emphasizes the balance between knowledge society and democratic economics to address challenges related to societal ecology and socio-economic environments (Huang and Wang, 2018).

From the preliminary overview of soapnut and typical enterprises, it is evident that the development of the soapnut industry relies on the industrial development environment and prospects, benefits from government policy guidance, support from relevant research and innovation institutions, as well as the active participation and support of farmers. Additionally, due to the uniqueness of agricultural production, the involvement of farmers is fundamental to the industrialization of soapnut. Following the theory of industry and value chains, innovation and research development are essential pathways for business growth. Therefore, based on the Quadruple Helix theory, we have constructed a Soapnut Quadruple Helix innovation ecosystem model (Figure 2) in order to facilitate knowledge exchange and innovative collaboration among government, universities, enterprises, and farmers, thereby propelling the spiral development of the local soapnut industry.

2.3 Role and effects analysis of comprehensive collaborative innovation in the soapberry industry chain

2.3.1 Practice application of the collaborative roles of government, university, enterprises, and farmers in the soapberry industry innovation ecological system

The innovative ecological model of the soapnut quadruple helix consists of four basic units: government, universities (research institutions), enterprises, and farmers (cooperatives). The organic integration of these four entities forms the foundation for collaborative innovation in the quadruple helix innovation ecosystem. The academic and industrial innovation chains are interlinked, creating the "government-production-learning-application" quadruple helix innovation ecosystem (Yang and Jiang, 2005).

1. As a leader and promoter of the green soapnut industry development, the government mainly fulfills its core functions by creating a macro environment, formulating policy guidance, and providing capital investment support.

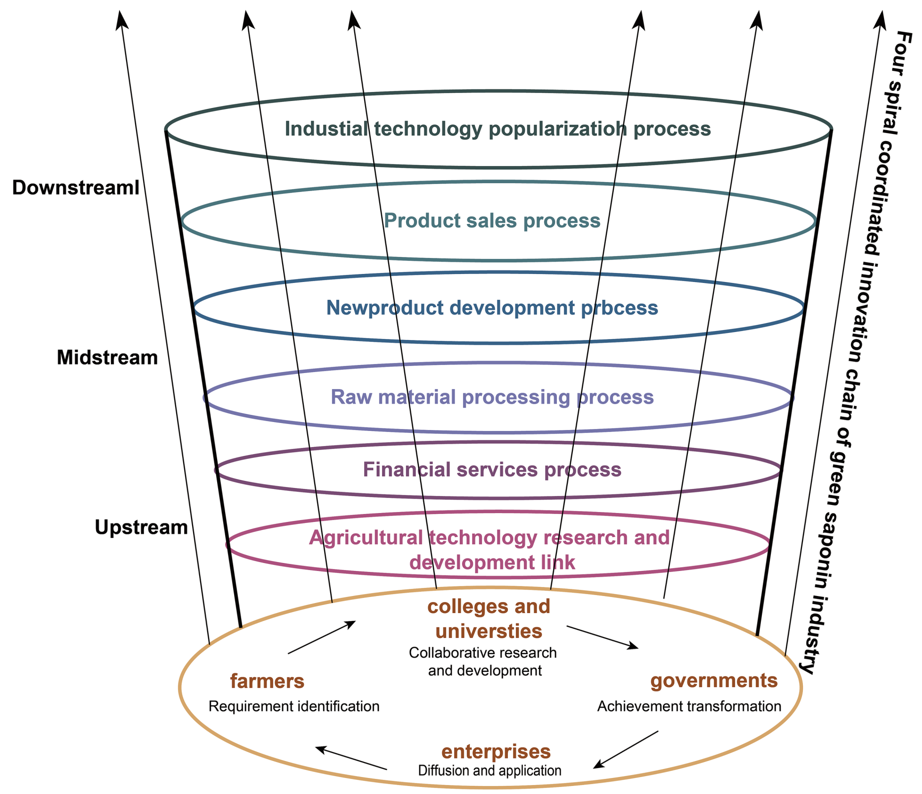

FIGURE 2
Quadruple helix innovation ecological model of green soap horn.

The government plays a key role in developing case enterprises, especially in the early stages of enterprise growth. For instance, the development of saponin industries has benefited from China's rural revitalization strategy and poverty alleviation background.

2. As innovators and promoters of green soapnut technology, universities offer essential technological and talent support for industrial development. Case enterprises collaborate with several agricultural universities and research institutions, obtaining crucial technological innovations in green soapnut product research and development through university-industry cooperation. From a value chain perspective, universities assist enterprises in research and development, production, sales, and technical personnel support.
3. As innovators and implementers of innovation outcomes, enterprises have a deep understanding of market and farmer needs and maintain close ties with the market. Building on the foundation of the macro policy environment and industrial competitive environment, case enterprises, lacking internal innovation capabilities, fully collaborate with other innovation entities to apply collaborative innovation outcomes to the industrialization process of soapnut products. This enhances competitiveness, increases farmers' incomes, promotes the transformation of traditional agricultural industry structures, and aids rural revitalization.
4. Farmers are beneficiaries of industrial green transformation and key implementers of collaborative innovation outcomes. The case enterprise in this study evolved from traditional herbal cooperatives and family farms, and its growth, along with the large-scale development of green Gleditsia, has boosted local employment and stabilized farmer incomes. Meanwhile, farmers' active participation facilitates the diffusion of innovation, contributing to agriculture's green and scaled development. Drawing on the Technology Acceptance Model (TAM), farmers' adoption of green technologies is significantly influenced by perceived usefulness and ease of use. For example, middle-aged farmers may acknowledge the economic benefits of new technologies but resist adoption due to the complexity of smart devices. Village-level demonstrations enhance perceived trust, highlighting the importance of interpersonal influence. According to the Diffusion of Innovations theory, farmers' adoption behavior follows a phased process: awareness often depends on offline training; decision-making is constrained by risk aversion; and implementation may be interrupted due to insufficient post-adoption support (e.g., reusing chemical pesticides). Structural barriers such as land fragmentation and the absence of opinion leaders (e.g., low participation of large-scale farmers) further hinder technology diffusion. Key enablers include financial incentives, user-friendly technologies, and organizational empowerment. A subsidy of 200 CNY per mu can increase adoption willingness, while "one-click" devices improve ease of use. Future efforts may include "field schools + local experts" for knowledge transfer, a risk-sharing mechanism among enterprises, insurers, and farmers, and establishing youth farmer innovation groups supported by demonstration fields—shifting farmers from passive recipients to active innovators.

2.3.2 Promotion of industrial diversification development by quadruple helix innovation ecological model

The quadruple helix innovation model, comprising government guidance, university research, enterprise operations, and farmer participation, forms a collaborative and complementary innovation network. This model not only enhances technological advancement and market expansion in the soapberry industry but also supports its diversified and sustainable development. Vertically, the model strengthens coordination across the value chain. In the upstream stage, universities assist in cultivar improvement and green planting technologies. In the midstream, enterprises collaborate with academia to develop eco-friendly processing methods, such as saponin extraction and natural surfactants. In the downstream, government-enterprise cooperation advances certification, branding, and e-commerce expansion. This integration of "knowledge-technology-product-market" improves value creation and reduces production inefficiencies (Wang et al., 2021).

Horizontally, the model fosters multi-level synergy among actors. Government policies provide financial and infrastructural support; universities enable knowledge transfer; enterprises engage farmers through contracts and training; cooperatives act as intermediaries linking all parties. This dynamic, non-linear system improves innovation performance and breaks traditional barriers in agricultural development. A practical example is Henan Hanyi Daily Chemical Technology Co., Ltd., which integrates local government resources and university expertise to build a full-chain soapberry industry involving over 1,000 farmers. The company expanded its product lines from 2 to 10, increased planting area by 50%, and raised farmers' annual income by over 3,000 RMB. This case illustrates how collaborative innovation drives industrial diversification and rural revitalization. The quadruple helix model enhances both vertical integration and horizontal collaboration, offering a replicable framework for advancing innovation-driven, diversified development in green agriculture.

Evaluation of Coordination Degree and Establishment of Index System for quadruple helix innovation ecosystem model.

2.4 Principles and methods for evaluating coordination degree of quadruple helix model

This study selects the harmonious development (HD) model as the core analytical framework for assessing the synergy among government, universities, enterprises, farmers, and intermediary organizations. Originating from systems science theory, the HD model focuses on structural coupling, dynamic equilibrium, and coordinated growth among subsystems. It is particularly effective for quantitatively analyzing collaboration among heterogeneous entities and is considered more appropriate than traditional efficiency-oriented approaches such as DEA and SFA (Yan et al., 2015). The model offers strong flexibility in handling multi-dimensional indicators and complex data structures, making it well suited for evaluating the interaction patterns within green agricultural systems involving diverse stakeholders. In the case of the soapberry industry's development in Queshan County, the HD model facilitates the evaluation of both individual actor contributions and the overall level of system coordination. This approach supports the identification of whether the system has achieved a collaborative state that generates shared value, which reflects the logic of cross-sectoral collaboration, system integration, and performance feedback in the context of green transformation. After a comprehensive comparison of existing evaluation methods and their relevance to the research objectives, the HD model was chosen as the most appropriate tool to assess the collaborative performance of the quadruple helix innovation ecosystem.

In accordance with the research by relevant scholars (Xue et al., 2010), the synergy model is formulated as follows. Additionally, the criteria for determining harmony (H) are outlined in Table 2.

1. Fundamental model

$$B = 1 - S / Y \tag{1}$$

In Formula 1, Y denotes the mean, and S represents the standard deviation. A larger value of B indicates a higher level of coordination among the various components of the system, reflecting better harmony, whereas a smaller value implies poorer coordination.

2. Model for Urban–Rural Coordination Coefficient. The formula for calculating the coordination coefficient between urban and rural areas is as follows:

$$C = \left\{ \frac{f(x) * f(y)}{\left\{ \frac{f(x) * f(y)}{2} \right\}^2} \right\}^K \tag{2}$$

In Formula 2, *f(x)* and *f(y)* represent the comprehensive development indices for urban and rural areas, respectively. Theoretically, a smaller deviation between *f(x)* and *f(y)* indicates greater coordination between urban and rural areas. Where C is the coordination coefficient, reflecting, under conditions where the development levels of urban and rural areas are constant, the maximum comprehensive coordination between urban and rural areas is achieved when the product of *f(x)* and *f(y)* is maximized. This signifies the hierarchical quantity of combined coordination between urban and rural areas, with $K \geq 2$.

To comprehensively assess the degree of coordination between urban and rural areas, a coordination development function is constructed utilizing C, *f(x)*, and *f(y)*:

$$D = \sqrt{C * T} \tag{3}$$

$$T = \alpha f(x) + \beta f(y) \tag{4}$$

In Formula 3 and 4, D represents the coordination development coefficient; C denotes the coordination coefficient; T stands for the composite evaluation index of urban and rural coordination development levels, reflecting the overall development levels of urban and rural areas. The parameters α and β correspond to the circles of the urban system and rural subsystem, respectively, with $T \in (0,1)$ and $D \in (0,1)$. The coordination development coefficient D integrates information on the coordination coefficient C and the overall development levels of urban and rural areas.

To ensure the objectivity, authenticity, and accessibility of the data, we conducted a comprehensive investigation of Henan Hanyi Daily Chemical Technology Co., Ltd., leveraging the development and exploration project of the Zaojiao ecological planting industry in Queshan County, Henan Province. This was achieved through interviews and on-site research involving the company's management personnel, employees, and local farmers. The specific survey content encompassed basic information about the interviewees and data concerning government, enterprise, university, employees, and impoverished groups.

2.5 Building an input–output indicator system for the four-helix innovative ecosystem model

To effectively evaluate the synergy of the quadruple helix innovation ecosystem in the soapberry industry, this study developed an input–output index system based on a comprehensive review of the literature and field research in Queshan County. Drawing on prior studies related to collaborative innovation and green agriculture (Yan et al., 2015; Li and Li, 2020; Yang and Liu, 2020), combined with field research data and practical characteristics of the soapberry industry in Queshan County. This ensures the scientific validity and contextual relevance of the index system. For input indicators, considering the role of government and universities as primary contributors, and enterprises as both input providers and outcome converters, eight dimensions were established to capture financial resources, knowledge input, human capital, and institutional support. These indicators aim to reflect key drivers in policy promotion, knowledge transfer, and organizational coordination (Lu, 2015).

Output indicators focus on enterprises and farmers as the main beneficiaries of collaborative innovation outcomes. Ten dimensions were selected to represent market performance, income growth, production efficiency, technology diffusion, and stakeholder satisfaction (Xue et al., 2010; Yan et al., 2015; Hu, 2016; Li and Tian, 2020). The selection prioritizes measurability, data availability, and local relevance, while also capturing the tangible contributions of each actor in the green innovation process.

It should be noted that due to strong regional heterogeneity and the diverse nature of farming populations in green agriculture, some indicators have inherent limitations. For example, subjective measures

TABLE 2 The determination criteria of coordination degree.

Coordination degree	$0.8 < H \leq 1$	$0.6 < H \leq 0.8$	$0.4 < H \leq 0.6$	$0 < H \leq 0.4$
Grade	Very collaborative	Compare coordination	General coordination	Uncooperative

such as satisfaction and training frequency may be influenced by perception bias, and long-term effects of collaboration may not be fully captured by short-term data. Future research may address these limitations through the inclusion of dynamic panel data and longitudinal tracking mechanisms. For specific indicator system and statistical characteristics, refer to Table 3.

3 Empirical study on the coordinated development of Zaojiao industry in Queshan County

Based on the overall research framework, this study evaluates the degree of synergy within the quadruple-helix innovation ecosystem by calculating the synergy coefficient H using the HR model (Table 4). The results show that the average synergy among government, universities, enterprises, and farmers is 0.6821, indicating a state of "relative synergy." This reflects an initial stage of effective collaboration among the actors, with particularly strong interaction observed between universities and enterprises. However, a closer examination of specific input–output indicators reveals persistent weaknesses in certain areas, suggesting that the system has yet to reach an optimal level of synergy. To improve the scientific rigor and interpretability of synergy classification, this study draws on the evaluation method for systemic synergy effects proposed by Song Yanqiu et al. (2020). Considering the data distribution and the life cycle characteristics of collaborative innovation in green agriculture, we adopt a four-level classification scheme. The synergy levels are defined as follows: high synergy ($H \geq 0.7$), medium synergy ($0.6 \leq H < 0.7$), low synergy ($0.5 \times H < 0.6$), and non-synergy ($H < 0.5$). These thresholds build upon established practices in the literature while accommodating the current growth stage of the soapberry industry, where the coordination mechanisms are still evolving. This classification enhances the empirical relevance of the model. Based on this framework, the synergy levels among various actors are detailed in Table 2. Within the overarching research framework, we primarily examined the degree of synergy in the innovation ecosystem of the Four-Helix model. With the assistance of the HR model, the synergy level H was computed, as shown in Table 4. Overall, the collaborative development among the government, universities, businesses, and farmers was calculated to be 0.6821, indicating a state of "relatively synergistic." To a certain extent, effective synergy has been achieved among the government, universities, businesses, and farmers, particularly in the efficient operation between universities and businesses. However, many instances of low synergy in input–output indicators still exist, indicating that the optimal synergy state has not yet been established. By analyzing the coordination status of segmented indicators, there is still room for improvement. The coordination levels among the government, universities, businesses, and farmers are divided into categories per Table 2. Specifically,

1. High synergy category

Based on the categorization in Table 2, "High Synergy" $H \in (0.8, 1]$, including 7 indicators such as joint government-business investments, various financial incentives from the government, university research funding, annual R&D investments by businesses, farmers' annual income per capita, farmer satisfaction, and the highest education level of senior management. Among these, the cooperation level of the highest education level of senior management is the highest, followed by farmer satisfaction. This can be attributed to several factors: firstly, establishing the case enterprise falls within the poverty alleviation period. With policy support and guidance, substantial investments were made by the government and universities, with high enthusiasm from all participants. As the poverty alleviation results solidify, subsequent support has decreased. Secondly, as an enterprise built on the foundation of rural cooperatives, it has a natural connection with local farmers, making it easier to mobilize their enthusiasm and achieve high-level cooperation and development between the enterprise and farmers. In summary, in the aforementioned indicators, the government, businesses, universities, and farmers should continue cooperating to ensure the harmonious operation of the entire innovation ecosystem, promote sustained benefits for farmers, and ultimately achieve regional development and revitalization.

2. Intermediate synergy category

As per the classification in Table 2, "Intermediate Synergy" $H \in (0.6, 0.8]$, specific indicators include the frequency of business meetings, annual skills training sessions, average income per acre, and the number of benefiting farmers. In terms of business meeting frequency and annual skills training sessions, the advancement of poverty alleviation efforts and the sudden impact of the COVID-19 pandemic may have led to reduced interactions between schools and businesses and between the government and businesses, with some businesses even halting production during the peak of the pandemic. Consequently, the synergy level of the above indicators has been affected. In terms of income per acre, with continuous government investment and ongoing business development, business profits have increased annually. However, from the perspective of the business lifecycle, it is still in the early operational stage with a limited market share. Therefore, there is room for improvement in the synergy of this indicator. Regarding the number of benefiting farmers, the case enterprise, established based on farmer cooperatives, has attracted many farmers to participate, driving local economic development and increasing farmers' economic returns. However, the scale of actual poverty alleviation and assistance should be expanded further to increase benefits. Thus, there is also room for improvement in the synergy of this indicator.

3. Low synergy category

According to Table 2 classification, "Low Synergy" $H \in (0.4, 0.6]$, mainly comprises five indicators such as the number of annual guidance sessions provided by universities, business market share, the number of signed contracts, business sales revenue, and the innovation contribution rate. As for the number of annual guidance sessions universities provide, some guidance has shifted to online communication due to the pandemic, potentially affecting its effectiveness. Furthermore, despite a gradual increase in guidance sessions, the quantitative changes have not translated into qualitative improvements, indicating the need to enhance the synergy of this indicator. In terms of market share, the number of signed contracts,

TABLE 3 Indicator analysis of enterprise innovation and farmer benefits in soap horn industry.

Indicator type	Indicator selection	Indicator characterization	Average value (2016)	Average value (2017)	Average value (2018)	Average value (2019)	Average value (2020)
Input indicators	Farmer work input	day	1,664	2,392	6,500	9,672	19,032
	Government and enterprise joint investment funds	10 thousand yuan	2,000	1,000	62	78.42	137.8
	Various government financial incentives	10 thousand yuan	4	4.25	5.3	5.5	5.5
	Annual guidance frequency of universities	Frequency	1	3	3.3	5.6	7.2
	University research funding	10 thousand yuan	8,000	9,000	7,500	10,100	12,000
	The highest education level of senior managers	1 = Primary school and below 2 = Junior high school 3 = High school and technical secondary school 4 = University and junior college 5 = graduate student	4	4	4	4	4
	Frequency of enterprise meetings	frequency	5	9	11.6	11.6	11.8
	Annual R&D investment of enterprises	10 thousand yuan	150	195	225	207.6	223.8
Output indicators	Enterprise market share	%	0.10	1	1	2	2
	Number of signed contracts	Number	5	20	10.8	18.3	20.8
	Per capita annual income of farmers	10 thousand yuan	0.6875	0.6825	0.7993	0.8455	0.8595
	Number of beneficiary farmers	Number	150	275	293	386	467
	Annual skill training frequency	Frequency	8	4	4	4.1	6.4
	Satisfaction of farmers	1 = very dissatisfied 2 = dissatisfied 3 = generally satisfied 4 = Satisfied 5 = very satisfied	4	4	4	4	4.75
	Average yield per mu	10 thousand yuan	4,360	5,610	7,180	8,570	10,900
	Enterprise sales	10 thousand yuan	670	1,100	1,510	2,160	2,360
	Honor level related to schools and enterprises	1 = Enterprise level 2 = County level 3 = prefecture level 4 = Province level 5 = National level	4	6	9	15	24
	Contribution rate of enterprise innovation	%	15	22	39	49	63

and business sales revenue, firstly, they are influenced by business strategic choices. The enterprise integrates raw material production, processing, and sales, with raw material production focused on maximizing market share and processed products focused on maximizing sales profitability, hence the slow growth in overall market share. Secondly, considering factors such as the regional and cyclical nature of soapberry production, the number of orders and market share growth has been slow. Regarding innovation contribution rate, issues regarding the applicability and practicality of collaborative outcomes may exist. Therefore, from the synergy perspective, there is still room for improvement in the synergy of the above indicators.

4. Non-coordination Category

As per Table 2 classification, "Non-coordination" $H \in (0, 0.4]$, involves two indicators: farmers' work input and school-business-related honors, both of which exhibit significantly lower levels of

TABLE 4 Synergy analysis of input and output indicators in enterprise development.

Indicator type	Indicator selection	Indicator characterization	Standard deviation	Average value	Synergy (H)
Input indicators	Government and enterprise joint investment funds	10 thousand yuan	319.8750	2,560	0.8750
	Various government financial incentives	10 thousand yuan	0.64992	4.91	0.8676
	Annual guidance frequency of universities	Frequency	2.1581	4.02	0.4631
	Farmer work input	Day	6296.5967	7,852	0.1981
	University research funding	10 thousand yuan	1609.2234	9,320	0.8273
	The highest education level of senior managers	1 = Primary school and below 2 = Junior high school 3 = High school and technical secondary school 4 = University and junior college 5 = graduate student	0	4	1
	Frequency of enterprise meetings	Frequency	2.6138	9.8	0.7333
	Annual R&D investment of enterprises	10 thousand yuan	27.4729	200.28	0.8628
Output indicators	Enterprise market share	%	0.7167	1.22	0.4126
	Number of signed contracts	Number	6.1183	14.98	0.5916
	Per capita annual income of farmers	10 thousand yuan	0.0760	0.77486	0.9019
	Number of beneficiary farmers	Number	107.1922	314.2	0.6588
	Annual skill training frequency	Frequency	1.6322	5.3	0.6920
	Satisfaction of farmers	1 = very dissatisfied 2 = dissatisfied 3 = generally satisfied 4 = Satisfied 5 = very satisfied	0.3	4.15	0.9277
	Average yield per mu	10 thousand yuan	2284.0368	7,324	0.6881
	Enterprise sales	10 thousand yuan	633.4350	1,560	0.5940
	Honor level related to schools and enterprises	1 = Enterprise level 2 = County level 3 = prefecture level 4 = Province level 5 = National level	7.2277	11.6	0.3769
	Contribution rate of enterprise innovation	%	17.49997	37.6	0.5346

"Honor level related to schools and enterprises" $= \sum(\text{honor level} * \text{number of projects})$.

synergy development compared to other indicators. Regarding farmers' work input, as the direct users of the collaborative innovation outcomes in the Four-Helix innovation ecosystem, the low level of cooperation in farmers' work input may be due to a mismatch in the supply and demand of human resources. Although there is an increasing trend in farmers' work input, the growth is insufficient to meet the demands of enterprises for related human resources. Moreover, an increase in the quantity of human resources does not necessarily equate to an increase in talent vitality and competitiveness, necessitating further improvement in the synergy of this indicator. In terms of honors related to schools and businesses, since the starting points and objectives of the cooperation innovation between universities and businesses differ, this will impact the low level of synergy in the indicator. Hence, there is also a need to enhance the synergy of this indicator.

4 Reconstruction, mechanism guarantee, and application promotion strategy of the four-spiral innovation ecological model under the strategy of rural revitalization

The previous analysis indicates that the quad-helix innovation ecosystem is in a state of "relative cooperation." However, a detailed analysis still reveals opportunities for improvement. Therefore, we have refined and restructured the existing model and proposed the practical application and dissemination of an optimized model based on the rural revitalization strategy.

4.1 Reconstruction of the four-spiral innovation ecological model

In rural revitalization strategy implementation, the reconstruction of the Four-Helix innovation ecosystem model needs to consider numerous factors. These include the external macro environment, regional economic development characteristics, saponin production situation, characteristics of innovative subjects, as well as the uniqueness of ecosystems in different regions, agricultural types, and ecological environments. Depending on the specific design objectives and considering various influencing factors from different perspectives of collaborative innovation models, the ultimate Four-Helix innovation ecosystem model under the background of rural revitalization will vary. For instance, the innovation ecosystem model incorporates regional specificity factors such as local economic conditions, cultural elements, and agricultural practices into its framework, enhancing adaptability and effectiveness. Given the intertwining nature of agricultural innovation ecosystems with their ecological environment, the model also takes into account the impact of ecological environmental factors such as biodiversity, soil health, water resources, and climate change. Based on the research analysis, we aim to construct a "Four-Helix + intermediary" collaborative innovation ecosystem model for rural revitalization, as illustrated in Figure 3. Essentially, the construction of a collaborative innovation model represents a fundamental step in driving the innovation of rural revitalization ecosystems, with the key lying in coordinating, managing, and applying supportive mechanisms for collaborative innovation.

1. Definition and composition of an innovation ecosystem

The emergence of the concept of "ecosystems" reflects a shift in the research paradigm, transitioning from focusing on the composition of elements within a system to examining the dynamic processes between elements and the interactions between the system and its environment (Zeng et al., 2013). Like biological systems, innovation ecosystems have evolved from the random selection of elements to structured communities. From a systemic perspective, companies are no longer just members of a single industry but part of ecosystems that span multiple industries. Within these ecosystems, companies continuously develop and enhance their capabilities through innovation, relying on collaboration and competition in product production to meet customer demands and drive ongoing innovation (Mei et al., 2014). The "Four-Helix + Intermediary" collaboration innovation ecosystem for rural revitalization is a complex, dynamic, and open system comprised of four main

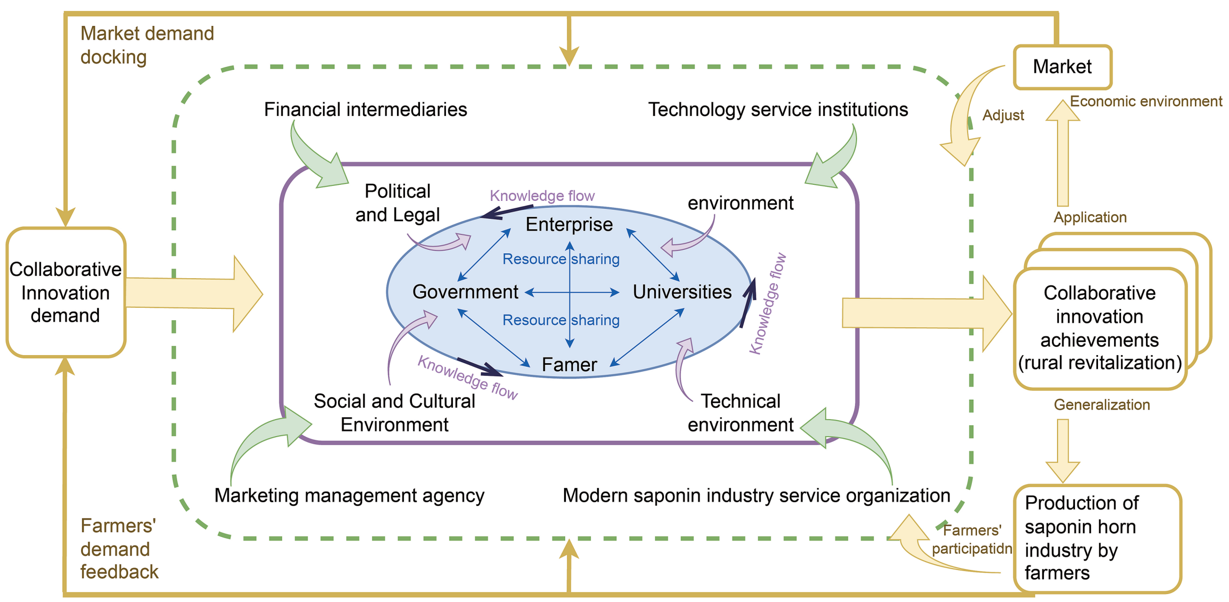

FIGURE 3
"Quadruple helix + intermediaries" rural revitalization collaborative innovation ecological model.

components: innovation actors, innovation objects, innovation goals, and innovation methods. The orderly and effective operation of this system benefits from the collaboration and cooperation among the various elements mentioned above.

Specifically, within the "Four-Helix + Intermediary" collaboration innovation model for rural revitalization, innovation actors consist of key entities such as enterprises, universities, government bodies, farmers, and intermediary organizations. Innovation objects primarily involve innovations in new production methods, processing techniques and forms, new varieties, new organizational mechanisms, and structures in collaborative innovation. The output of collaborative innovation includes agricultural patents, new plant varieties, geographical indications, trademarks, and trade secrets. Innovation methods mainly encompass the means and tools for collaborative innovation and the mechanisms for collaborative operation. Innovation means, and tools refer to the technological or methodological approaches taken by innovation actors toward innovation objects for specific innovation purposes, including computer-based methods or technologies for gathering information. The mechanisms for collaborative innovation operation primarily entail the tasks, responsibilities, procedures, rules, policy coordination mechanisms, legal protection mechanisms, interest distribution mechanisms, clear property rights systems, and outcome protection mechanisms within collaborative innovation.

2. The main functions and positioning of the innovation ecosystem

The "Four-Helix + Intermediary Organization" rural revitalization cooperation and innovation ecosystem model integrates the production, study, and research operational mode by incorporating government policy adjustments and legal protection mechanisms. This is because the government can enhance the initiative of innovation entities to participate in collaborative innovation by formulating policies and laws, guiding and regulating their specific collaborative innovation behaviors. Throughout the process of collaborative innovation, considering the distinct characteristics, relationships, and functional orientations of various innovation entities, intermediary organizations should play a crucial role in management, coordination, communication, and service provision within actual collaborative innovation practices. For instance, when evaluating collaborative innovation outcomes and distributing benefits, third parties led by intermediary evaluation or management entities conduct outcome assessment and benefit distribution. This approach results in more impartial evaluations and fairer benefit distributions, mitigating conflicts arising from imbalanced benefit distribution among innovation entities. Therefore, intermediary organizations such as management operations, technical services, financial services, and modern agricultural services should be introduced upon the aforementioned collaborative innovation model. This study incorporates additional empirical analysis to further examine the functional role of intermediary organizations within the quadruple helix innovation ecosystem. Using the under-forest intercropping model as a case, a "company–cooperative–farmer" operational mechanism was implemented, supported by a "guaranteed return + incentive" income distribution scheme. Based on input–output accounting, farmers receive guaranteed compensation for land and labor, while any yield exceeding the baseline is distributed at a 70:30 ratio between farmers and cooperatives. This model breaks the traditional top-down structure of cooperatives, enhances farmers' participation incentives, and fosters a more balanced and collaborative innovation framework. Leveraging their marketing channels and operational experience, intermediary organizations have significantly expanded market access for Gleditsia products, thereby enhancing the commercialization of collaborative innovation outcomes and improving the overall performance of the quadruple helix system. Furthermore, from the perspective of innovation diffusion, farmers are not merely beneficiaries but also direct users of new technologies. Their practical needs serve as a critical point of departure for collaborative innovation. Therefore, in designing the collaborative model for the Gleditsia industry, the central role of farmers should be further emphasized.

In conclusion, constructing the "Four-Helix + Intermediary Organization" rural revitalization cooperation and innovation ecosystem model in the soapberry industry is a theoretical, historical, and practical necessity based on the Chinese soapberry industry's current production and development status. Rooted in systems theory, collaborative theory, technology diffusion theory, and economic development theory, this model is a logical outcome of theory, historical evolution, and practical requirements and represents the inevitable product of technological innovation development to a certain stage.

4.2 Mechanisms ensuring the innovation ecosystem model

Indeed, the cooperative and innovative rural revitalization model of "four helices + intermediary organizations" mentioned above is a product of theoretical logic, historical development, and practical needs. It is also an inevitable outcome of advancing science and technology innovation. However, the operation of this collaborative innovation model is contingent upon corresponding policy safeguard mechanisms, which can be specifically designed from the following four aspects.

Firstly, enhancing the internal management and functionality of the "four helices + intermediary organizations" rural revitalization cooperative innovation ecosystem is imperative. Before policy implementation, it is necessary to clearly define the responsible entities for each policy measure, including government departments, enterprises, universities, intermediary organizations, and farmer representatives, ensuring that each policy has a designated executor. Implementing a multi-tier supervision mechanism involving internal government oversight, higher-level government supervision over lower-level government bodies, and external oversight by social organizations and the public is vital for ensuring the transparency and fairness of policy implementation. Moreover, policy implementation should not remain static; adjustments and optimizations to policy measures should be made promptly in response to issues and challenges encountered during execution. This necessitates the establishment of a feedback mechanism to collect feedback and suggestions from various stakeholders as a basis for policy adjustments. Regular professional training should be provided to policy implementers to enhance their understanding and execution capabilities. Additionally, policy interpretation and implementation guidance should be offered to the target groups, particularly grassroots farmers, to ensure accurate comprehension and effective execution of policy measures. Finally, establishing an information-sharing platform to publicly disclose policy implementation's progress, effectiveness, and evaluation reports is crucial for accepting oversight from the general public and relevant stakeholders. The innovative ecosystem model serves as a vital organizational vehicle for enhancing the efficiency of multi-system cooperation and plays an irreplaceable role in driving green agricultural development (Yan et al., 2015). Currently, China's normative application of the four-helix innovation ecosystem model in institutional construction and governance structure is insufficient, necessitating further elevating its internal governance standards to facilitate continuous improvement of the model's functionality. In practice, there is a specific need to bolster demonstration and promotion efforts to increase farmers' income, encourage active participation in the model, and improve the return rate on their involvement in the ginseng industry (Yan et al., 2015).

Secondly, establish a collaborative development mechanism for the "four helices + intermediary organizations" rural revitalization cooperative innovation ecosystem. Creating a regular communication platform among government, enterprises, universities, and farmers to exchange cooperation progress and share information and resources is essential. Simultaneously, devising a clear profit-sharing mechanism to ensure equitable distribution of innovative outcomes among all parties through formalized contracts or agreements is crucial. Tailoring more refined supportive policies based on the characteristics of different regions and agricultural types is necessary to provide targeted financial, technological, and market support. Furthermore, it is essential to foster deep cooperation between universities, research institutions, and enterprises to accelerate technology research and its application in agricultural production. Regarding evaluating collaborative effects, efficiency measurement models should primarily assess the collaborative efficiency of all parties involved regarding information sharing, resource allocation, and benefit sharing. Additionally, environmental monitoring and ecological assessments should be conducted to analyze the impact of innovation activities on the ecological environment to ensure the eco-friendliness of agricultural innovation activities.

To strengthen the institutional foundation for green agricultural innovation, this study draws on local practices in Queshan County and broader domestic and international experience to propose several financing mechanisms tailored to different regional contexts. First, public-private partnership (PPP) models can be applied to infrastructure development. For example, Queshan could establish a Gleditsia processing park through a PPP framework, with the government funding land preparation and basic infrastructure (40%) and enterprises investing in production equipment (60%), sharing profits proportionally. A similar model in Yunnan's macadamia industry reduced construction time by 30% and achieved an 8% return on social capital, demonstrating its applicability to underdeveloped regions. Second, green bonds can support the scaling of eco-friendly technologies. A proposed example is issuing RMB 50 million in carbon-based green bonds for the intelligent upgrading of Gleditsia plantations, with repayment covered by carbon trading revenues (estimated at RMB 5 million annually) and government interest subsidies (RMB 2 million annually). Third, targeted microfinance mechanisms, such as "green technology adoption micro-loans," can enhance financial inclusion. Queshan could collaborate with rural credit unions to launch a "Gleditsia Innovation Loan," offering unsecured credit of up to RMB 50,000 per farmer for inputs like bio-fertilizers or smart devices, with interest subsidies provided by local authorities. A complementary "enterprise-backed guarantee pool" would raise loan ceilings to RMB 100,000, lowering borrowing barriers. International models such as India's SKS have shown repayment rates of 97% and a 58% increase in technology uptake. Lastly, to mitigate investment risks and encourage financial participation, a green agricultural risk compensation fund could be established (jointly funded by central and local governments at a 3:2 ratio), offering partial coverage for PPP losses (30%) and green bond defaults (50%). Additional tax incentives—such as reduced income tax rates for green lending institutions—alongside the inclusion of green financing metrics in local government performance evaluations would further strengthen policy guidance and market confidence.

Thirdly, enhance the main functions of the "four helices + intermediary organizations" rural revitalization cooperative innovation ecosystem. Improving and coordinating the main functions of innovation is a crucial guarantee for the effective operation of this model. In the rural revitalization cooperative innovation ecosystem, maximizing the various key functions of innovation and emphasizing the regulatory role of third-party intermediary organizations are essential for promoting the healthy operation of the collaborative mechanism. In the development of the green ginseng industry, the diffusion and transfer of innovation outcomes typically occur within the system, with minimal influence from external resources. Therefore, utilizing intermediary organizations such as financial, marketing, technological, and industrial service providers to drive the flow of factor resources is essential for enhancing the value of the industrial chain.

Fourth, to enhance the practical applicability of policy recommendations, this study proposes implementation pathways based on Queshan County's experience and comparable regional cases, focusing on fiscal support, technology transfer, and farmer training. For fiscal support, a tiered funding mechanism is recommended. A central green agriculture innovation fund should allocate resources based on regional development levels. In less-developed areas like Queshan, direct subsidies (e.g., ¥200 per mu for technology adoption) and performance-based rewards (e.g., ¥50,000 for cooperatives engaging 10 + farmers) can be applied. In developed regions, PPP models may be more effective in leveraging private investment. For technology transfer, a demand-driven mechanism is advised. Agricultural service centers identify frontline production needs (e.g., pest control), commission targeted R&D, and verify results through on-site trials (e.g., field labs). Evaluation metrics, such as ease of use, ensure the outputs are practical and farmer-friendly. For training, a tiered model is proposed. Basic-level programs combine VR simulation with field practice to accelerate skill acquisition, while advanced-level training includes field visits and peer learning. A "lead farmer + follower" mentorship scheme is also suggested, with government incentives tied to demonstrated technology diffusion outcomes, encouraging a shift from passive reception to active participation.

4.3 Application and promotion of the innovation ecosystem model

In the context of rural revitalization strategy, based on the analysis above, the "Four Spirals + Intermediary" rural revitalization cooperation and innovation ecosystem model can be practically applied and promoted in the following five areas:

1. In rural revitalization, it is imperative to identify suitable industries based on local conditions and garner support from governmental and academic entities to stimulate local farmers. Taking the soapberry industry as an example from the study, it capitalized on the region's cultivation history and existing industry scale, with companies established on the foundation of current cooperatives. Continuous development led to the formation of an industrial cluster centered around soapberries, known as the "one industry driving one industrial cluster" concept (Cui and Su, 2012). The soapberry industry not only boosted local farming and manufacturing sectors but also catalyzed the growth of local e-commerce and technology services, facilitating the translation and application of research outcomes from universities and research institutions and significantly enhancing the revitalization of industries that play fundamental roles in rural development.
2. Concerning talent revitalization in rural revitalization, leveraging the cooperative innovation model can facilitate the rapid dissemination of knowledge and patents between universities and research institutions, enhancing enterprise production management capability and farmers' overall quality. Building upon this, universities, enterprises, and farmers can collaborate to establish a platform similar to a joint knowledge dissemination center. Through this platform, university professors and research personnel can regularly participate in lectures, analyzing and addressing issues enterprises and farmers face. Additionally, universities and research institutions can offer specialized pathways for enterprises and farmers to further their education, cultivating local talents at scale to ultimately serve local development. Through this development, local human resources can transform into human capital, imbued with talent, vitality and competitiveness.
3. Regarding cultural revitalization in rural revitalization, intermediaries can facilitate the dissemination of local unique culture, where cultural promotion can also drive the development of local tourism and distinctive industries. Incorporating local customs and culture into product promotion processes can achieve integration between industry and culture. Furthermore, the government can promote local culture through platforms such as streets or television stations, while universities and research institutions can assist in cultural creation, product design, and marketing management. For instance, a company highlights the inheritance of red culture and green environmental concepts in its product production and sales processes. Universities collaborate with marketing professionals to enhance the company's product design and marketing methods, infusing traditional cultural elements into the designs, facilitating cultural dissemination and revitalization during product promotion.
4. Under the rural revitalization strategy, ecological and organizational revitalization are key pillars supporting sustainable green agriculture. Governments and enterprises play leading roles in ecological revitalization, with universities providing technical and knowledge support. Many rural areas in China still retain relatively untouched ecosystems, which require protection alongside high-quality development. Governments should implement ecological protection policies and partner with universities and social organizations to promote environmental education and awareness. Enterprises must comply with environmental standards and advance green production to align ecological and economic goals. As the foundation for industry, culture, and talent development, a healthy environment is essential to comprehensive rural revitalization. Organizational revitalization requires strengthening village governance systems, particularly in grassroots party branches, self-governance bodies, collective economies, and local social organizations. Agricultural cooperatives, as intermediaries between enterprises and farmers, enhance village organizational capacity and empower farmers in decision-making. Local organizations—cultural institutions, e-commerce teams, and conservation groups—serve as vital connectors in the "quadruple helix + intermediary" ecosystem, facilitating product marketing, cultural transmission, and policy implementation. To enhance the regional adaptability of the model, this study examines differences in economic context, cultural background, and agricultural development stages. Developed regions (e.g., Anji, Zhejiang) benefit from research infrastructure and innovation platforms, while less-developed areas (e.g., Queshan) rely on policy support and intermediary coordination. Culturally, collectivist regions are suited to standardized production via cooperatives, while fragmented regions (e.g., Ningde, Fujian) depend more on digital platforms. Ethnic regions (e.g., Dali, Yunnan) can integrate local culture with branding. Traditional zones should focus on technology diffusion and talent training at different agricultural stages, modern areas (e.g., Shouguang, Shandong) on deeper industry–research integration, and urban or advanced zones (e.g., Chongming, Shanghai) on globalized collaboration and sustainable innovation.
5. Regarding organizational revitalization in rural construction, special attention should be paid to the construction of rural organizations, the organizational capacity of grassroots cadres, and the development of social organizations. Rural organizations can be categorized into four types: rural grassroots party organizations, villagers' self-governing organizations, village-level collective economic organizations, and rural social organizations. These four types of organizations encompass governmental bodies and civil society organizations. For instance, agricultural cooperatives formed by enterprises and local farmers enhance the village's organizational capacity and empower farmers with more say in cooperative agreements. Furthermore, developing local social organizations is crucial, playing significant roles in cultural dissemination, live streaming, product sales, and more. Additionally, local industry associations, ecological protection organizations, and other intermediaries between the government and the public act as intermediaries, effectively promoting interaction between the government and farmers and propelling the rural construction process.

5 Conclusion

In the context of rural revitalization strategy, this paper analyzes the theoretical logic of the innovation ecosystem of the soapberry quadruple helix, calculates its synergistic effect, and reconstructs the soapberry quadruple helix innovation ecosystem model. It introduces a cooperative innovation model based on the quadruple helix theory called "quadruple helix + intermediary." Finally, the paper discusses the promotion and application of the aforementioned model based on the rejuvenation of industries, talents, culture, ecology, and organizations in rural revitalization. Three main research conclusions are drawn as follows:

Firstly, the formation of the soapberry quadruple helix innovation ecosystem has a solid theoretical basis. It evolves from the triple helix and refines the traditional "civil society" into "farmers" as the innovation entity within the quadruple helix. This forms a biological system based on the industry chain, supply chain, and innovation theory, encompassing the functions and positioning of key innovation entities such as government, enterprises, universities, and farmers. The paper also discusses the developmental path of the model both horizontally and vertically, taking into account the development of the soapberry industry.

Secondly, the overall synergistic development of the soapberry quadruple helix innovation ecosystem is relatively coordinated but still has room for optimization. Research shows that the overall synergistic development level of the quadruple helix innovation ecosystem is 0.6821, indicating a "relatively coordinated" status. However, there is room for optimization in most of the levels of synergy, including "non-coordinated," "partially coordinated," "relatively coordinated," and "highly coordinated," especially concerning the input of farmers' work and university-enterprise collaborative honors.

Thirdly, the "quadruple helix + intermediary" rural revitalization cooperative innovation ecosystem model is established. Against the backdrop of the rural revitalization strategy, the paper optimizes and reconstructs the quadruple helix innovation ecosystem model, defines the composition of the "quadruple helix + intermediary" collaborative innovation model, elaborates on its key functions and positioning, and highlights the roles of government, enterprises, universities, farmers, and intermediary institutions in collaborative innovation. Furthermore, mechanisms to ensure the effective operation of the model are proposed, including policy support, functional improvement, mechanisms for collaborative development, and enhancements of the functions of innovation entities. Lastly, specific application directions of the model are showcased, supporting the implementation of the rural revitalization strategy comprehensively in areas such as industrial revitalization, talent development, cultural rejuvenation, ecological protection, and organizational revitalization. This comprehensive analysis not only offers a new innovative development model for the soapberry industry but also provides a cooperative innovation framework that similar industries can emulate.

Fourth, to enhance the scalability of the "quadruple helix + intermediary" model across diverse agricultural settings, this study proposes a flexible framework tailored to industry type, regional characteristics, and development stage. In high-value crop areas, emphasis should be placed on university-enterprise collaboration and intermediary-facilitated market access. In staple grain regions, government-farmer cooperation supported by policy finance and cooperatives is essential. Ecologically sensitive zones benefit from environmental intermediaries and mechanisms that monetize ecosystem services. For fragmented, mountainous regions, industrial alliances and enclave-based coordination help standardize production. Model parameters should be adjusted accordingly: increase R&D investment for technology-intensive sectors, strengthen farmer training intermediaries in labor-intensive ones, apply PPP financing in underdeveloped areas, and promote venture capital in advanced regions. This adaptive design enhances the model's transferability and supports diversified, replicable solutions for sustainable rural revitalization.

Based on the proposed research framework and methodology, this study has yielded key findings and policy recommendations. However, several limitations should be acknowledged. First, due to COVID-19 constraints, data collection relied primarily on telephone interviews and email surveys, which may have affected the representativeness and completeness of the data. Some respondents may have been unable to fully express their perspectives through remote communication, resulting in potential information gaps. Future studies could adopt a mixed-methods approach, combining field interviews, structured questionnaires, and participatory observation to enhance data richness and reliability. Incorporating longitudinal data and cross-regional comparisons would further validate the applicability and robustness of the "Quadruple Helix + Intermediary" model. Second, the findings are mainly drawn from the case of the soapberry industry in Queshan County, which may limit the generalizability of the conclusions. Future research will expand the industry scope and regional coverage to improve the model's universality and practical relevance.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

QC: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft. JL: Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The author(s) declare that no Gen AI was used in the creation of this manuscript.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2025.1531810/full#supplementary-material

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