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Multi-Scale Evaluation and Simulation of Livelihood Efficiency in Post-Poverty Mountainous Areas

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Abstract: Promoting the coordination of livelihoods at the county and farmers' scales is essential for achieving balanced regional development and rural revitalization in post-poverty mountainous areas. Existing studies predominantly focus on farmers' or regional livelihood capital and livelihood efficiency at a single scale, lacking research on cross-scale coordination between farmers' and county livelihoods. Consequently, these studies fail to reveal the interactions and synergistic enhancement pathways between the two scales. This study, using the Qinba mountains in southern Shaanxi as a case, employs system dynamics to construct a coupled system dynamics model of farmers' livelihood efficiency and county livelihood efficiency. From the perspective of livelihood capital, five regulatory modes, comprising a total of 17 scenarios, were designed and simulated. The results indicate the following data: (1) The coupling coordination degree between farmers' livelihood efficiency and county livelihood efficiency in the Qinba mountains is 0.623, indicating a moderate level of coordination overall. However, the coupling coordination relationship requires further optimization and adjustment. Specifically, Foping exhibits a severe imbalance, while the coupling coordination degree of Shiquan, Zhashui, Baihe, Pingli, and Lan'gao is in a state of basic coordination. Additionally, 19 other counties, including Lueyang, Ningqiang, Yang, and others, exhibit moderate coordination. (2) Enhancing social or financial capital through various means typically promotes the coordinated development of farmers' and county livelihood efficiency. On average, social capital and financial capital regulation models can increase the coupling coordination degree by 0.08 and 0.17, respectively. Additionally, strategies such as increasing fixed asset investment and regulating other capital types, including reducing arable land, also effectively improve the coupling coordination degree of farmers' and county livelihood efficiency. This study provides a decision-making basis for improving the coordination of farmers' and county livelihoods in post-poverty mountainous areas, thereby promoting economic development and intensive resource utilization. It assists in formulating more precise policy measures and offers a reference for sustainable development and rural revitalization in similar regions.

Keywords: livelihood efficiency; post-poverty mountainous areas; coupling coordination; system simulation; multi-scale

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1. Introduction

With the continuous advancement of China's rural revitalization strategy, the interaction between farmers' livelihood activities, natural resources, and socioeconomic conditions at the county level has become crucial for achieving high-quality development. Related research indicates that livelihood capital serves as the foundational resource individuals or groups use to sustain their livelihoods and achieve development [1]. Livelihood efficiency refers to the effectiveness and outcomes of individuals or groups utilizing limited capital to achieve their livelihood goals [2–4]. From an economic perspective, Pareto efficiency theory

and externality theory provide valuable insights. Pursuing maximized efficiency in one subsystem can reduce efficiency in another, thus failing to achieve overall optimization [5,6]. From a sociological perspective, focusing solely on the livelihood efficiency of farmers or counties may overlook social equity and long-term development. It is necessary to promote resource and risk sharing through the optimization of social capital to achieve coordinated development and ensure the sustainability of livelihoods. In practical development, improving the coordination between farmers' livelihoods and county livelihoods can lead to more effective resource allocation and promote overall rural development. Therefore, evaluating and simulating livelihood efficiency at multiple levels is essential for optimizing resource allocation, maintaining ecological balance, ensuring social equity, and achieving common prosperity.

In fact, 'livelihood efficiency' is a relatively new concept, first introduced by Su Fang in 2021 [4]. It provides a relatively comprehensive measure of the livelihood activities of individuals or groups. Currently, there is limited research directly focused on livelihood efficiency. However, many scholars have applied efficiency assessments to specific aspects of livelihood activities, providing important references for this study. For example, some researchers have used data envelopment analysis or stochastic frontier models to study resource utilization efficiency in sesame cultivation in Ethiopia [7], corn farming in Ghana [8], and rice production in the Philippines [9]. While these studies reflect, to some extent, the effective utilization of agricultural resources and the management decision-making capabilities of farmers, they lack a comprehensive assessment of all livelihood activities.

Currently, research on the 'multi-scale evaluation and simulation of livelihood efficiency' mainly focuses on the following three aspects: First, the impact of livelihood capital on livelihood strategies and livelihood security. Studies have shown that optimizing the allocation of livelihood capital effectively improves farmers' livelihood efficiency [10], promotes the diversification of livelihood strategies [11], and ensures regional livelihood security [12]. For example, increasing education and skills training can enhance human capital, thereby encouraging households to adopt advanced technologies and management methods [13,14], raising environmental awareness [15,16], and improving the yield and quality of agricultural products [17]. However, some scholars find that effective livelihood improvement requires sufficiently long project cycles and substantial trust from farmers toward partners [18,19]. Additionally, the prudent use of financial capital, such as microcredit and agricultural insurance, helps farmers cope with market and natural risks, thus stabilizing livelihood efficiency [20–22]. Second, the livelihood capital, strategies, and influencing factors affecting different types of farmers. Farmers' livelihoods are influenced by various factors, including geographical location [23], resource endowment [24], social capital [25], policy support [26], and natural disasters [27]. Research indicates that different types of farmers vary in their access to and utilization of livelihood capital, directly affecting their capital levels and strategy choices [28,29]. Furthermore, the enhancement of livelihood capital usually drives farmers to shift toward diversified livelihood strategies [29,30], benefiting technical efficiency and household income [31]. However, changes in livelihood choices require context-specific analyses. Third, exploring ways to promote the coordinated development of livelihood systems with other socioeconomic systems through interventions. Precise interventions can directly improve livelihood conditions and resource utilization efficiency, fostering the overall coordinated development of socioeconomic systems [32,33]. However, the impact of different interventions on livelihood systems can vary significantly [34], with some policy interventions potentially increasing the economic burden on farmers [35]. Conversely, appropriate interventions can stimulate farmers' innovation and adaptability, thereby achieving the dual goals of livelihood improvement and economic development [36]. Therefore, when designing these interventions, the complexity and variability of livelihood systems must be considered to ensure that appropriate methods and measures are adopted for each region [37].

Overall, existing studies provide significant insights into the coupling mechanisms and system modeling of farmers' and county livelihood systems, but there are opportu-

nities for further exploration. First, while the current literature often evaluates farmers' and county livelihood systems in terms of livelihood diversity [38], resilience [39], and strategy choices [40], research from the perspective of efficiency is relatively limited. Some scholars measure the outcomes of farmers' livelihood activities and their ability to withstand risks using livelihood capital. However, this approach overlooks the subjective initiative of farmers in rationally utilizing resources [2]. Second, some scholars argue that farmers' livelihood types [41], industrial development [42], and natural resources [43] are the main factors affecting livelihood levels, but a few studies have observed changes in livelihood states through system simulation methods. Third, existing research has separately evaluated farmers' livelihood efficiency [44] and regional livelihood capital [45]. It has recognized the bidirectional feedback relationship between farmers' livelihood strategies and regional livelihood capital [1,46]. However, no scholars have yet constructed an integrated system of farmers' and county livelihood systems to analyze their coupling and coordination dynamics.

Based on this, the main objective of this paper is to explore the coupling coordination of livelihood systems at both the farmer and county scales, along with their regulation strategies, from the perspective of livelihood efficiency, in order to realize sustainable livelihood development. It should be noted that the 'coupling coordination' here emphasizes that the livelihood systems of farmers and counties are equally important and work together. The two systems can optimize their respective resource allocation and strategies through positive interactions, thus maximizing overall benefits and jointly promoting the sustainable development of regional livelihoods. Specifically, the main objective can be refined into the following key questions: First, how can we construct and measure the farmers' and county livelihood efficiency in post-poverty areas? Addressing this question can provide a solid data foundation for subsequent analysis and help us understand the status of livelihoods at different levels. Second, what is the coupling relationship between farmers' livelihood efficiency and county livelihood efficiency? By exploring this relationship, the coupling mechanism of the multi-scale livelihood efficiency system can be revealed, providing theoretical support for policy formulation. Third, what appropriate regulatory measures can be taken to promote the coordinated improvement in farmers' livelihood efficiency and county livelihood efficiency? This question focuses on exploring strategies at the practical level. With the help of scenario simulation and analysis using the system dynamics approach, practical suggestions can be provided to local governments and related organizations to promote the overall coordination and sustainable development of the livelihood system.

To address the aforementioned key issues, this paper consolidates the team's survey results of farmers in the Qinba mountains of southern Shaanxi and related statistical data. Using the DEA model, we separately measure the livelihood efficiency of farmers and counties. We then select various macro and micro elements to construct a system dynamics model that includes farmers' livelihood efficiency and county livelihood efficiency. By altering certain parameters, we conduct scenario analyses under different livelihood capital change models. Our goal is to provide valuable insights for guiding farmers and counties toward sustainable livelihoods, fostering coordinated development between farmers and counties, and contributing to rural revitalization efforts. It is noteworthy that we focus our research on the post-poverty mountainous areas, which have significant practical significance and theoretical value. In 2020, China achieved comprehensive poverty reduction, eliminating absolute poverty, marking the transition of formerly impoverished areas into the "post-poverty" era [47]. However, escaping poverty does not imply that China has achieved its development goals in the new era [48]. On the contrary, how to consolidate the achievements of poverty reduction, promote rural revitalization, and achieve common prosperity has become a new challenge [49]. This is especially true in mountainous areas with relatively unfavorable geographical conditions, where improvements in livelihoods and county development continue to face numerous difficulties [50], necessitating our ongoing attention and research.

The possible marginal contributions of this paper mainly include three aspects. First, this paper constructs a measurement system of farmers' livelihood efficiency and county livelihood efficiency, combining the entropy method and the DEA model with variable returns to scale. This approach scientifically assesses the livelihood efficiency of farmers and counties in the Qinba mountains area, further enriching the relevant research on sustainable livelihoods. Second, this paper uses the system dynamics method to outline the main variable relationships and feedback loops between the farmers' livelihood system and the county livelihood system. It integrates these efficiencies into a complex coupled system, clearly describing the social network and interaction between farmers' livelihoods and county livelihoods. This provides new ideas and methods for understanding economic feedback and synergistic development at both macro- and microscales, avoiding the problems of endogeneity and statistical bias associated with traditional econometric models. Third, this paper designs and simulates 17 different regulatory modes from the perspective of livelihood capital based on actual research on farmers and the development situation of the county. This provides references for government policy formulation and farmers' strategy choices, helping to promote livelihood development in the Qinba mountains area and other post-poverty regions.

2. Materials and Methods

2.1. Overview of the Study Area

The Qinba mountains area in southern Shaanxi is located at the southern foot of the Qinling mountains, encompassing 28 districts and counties in the cities of Hanzhong, Ankang, and Shangluo (Figure 1). It covers about 70,400 square kilometers, with a resident population of approximately 7.7 million and a 2020 gross domestic product (GDP) of 342.164 billion yuan. The region is a national key ecological reserve and a post-poverty mountainous area, shouldering a major mission of promoting ecological balance and sustainable economic development. In terms of physical geography, the region has a favorable climate and unique biodiversity, which are conducive to agricultural production and farmers' livelihoods. However, it also faces the risk of ecological fragility and the potential return to poverty, which may affect the stability of farmers' livelihoods and challenge the resilience of county livelihoods as a whole. On the socioeconomic front, economic development is dependent on traditional agriculture and lacks industrial upgrading and innovation drive due to terrain, financial, and technological constraints. This limits the diversification of farmers' livelihoods, which in turn affects the structure and development potential of livelihoods in the county as a whole. Therefore, finding effective paths to optimize the patterns of farmers' livelihoods, enhance county livelihood efficiency, and ensure the coordinated and sustainable development of both has become a strategic need to achieve comprehensive rural revitalization and common prosperity.

2.2. Data Sources

The basic data for the subsystem of farmers' livelihoods come from a field survey conducted by our research team in August 2020 in the Qinba mountains area of southern Shaanxi Province. A total of 451 valid questionnaires were obtained after rigorous data screening. This survey employed a stratified random sampling method to select the interviewed farmers as samples. Specifically, there are 28 districts and counties in the southern Shaanxi Qinba mountains area. Due to objective constraints such as time, scheduling conflicts, and the distribution of investigators, we actually visited 25 of these districts and counties, thereby ensuring the diversity and representativeness of the samples. Based on the widespread application of mean estimation in stratified random sampling [51], we divided the towns in each county into two groups according to whether their per capita GDP is above or below the county's average. We then randomly selected one town from each group to ensure that the sample more comprehensively reflects the overall characteristics. Next, we applied the same method to divide the villages in each town into two groups

based on annual income and randomly selected one village from each group. Finally, we randomly selected 6–8 farmers from each chosen sample village.

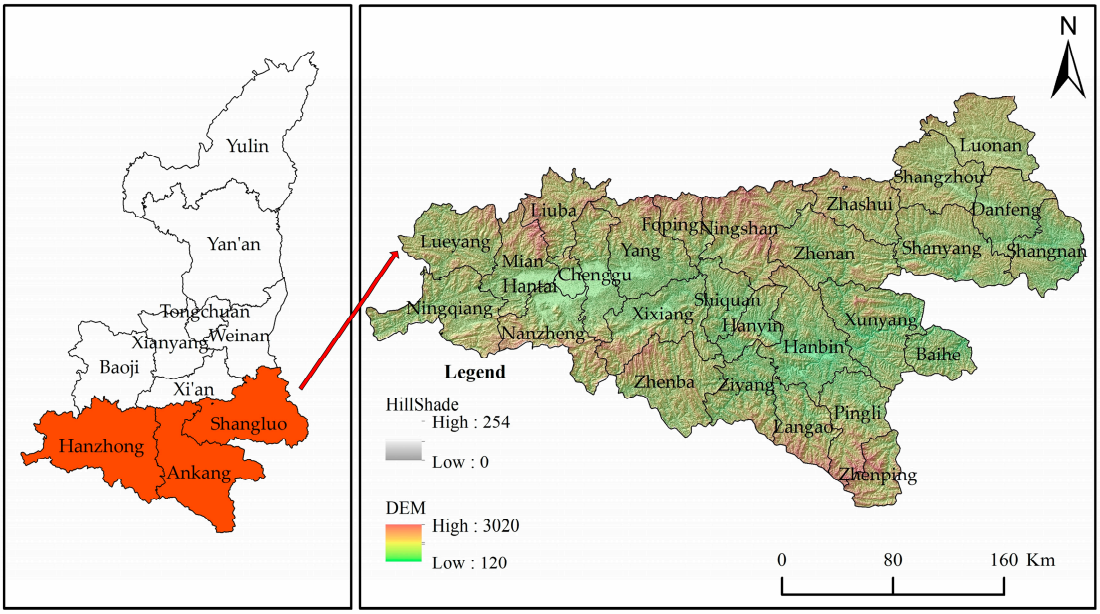


Figure 1. Location and Administrative Divisions of the Three Cities in the Qinba Mountains area of Southern Shaanxi. Note: This figure is based on the standard map with review number GS(2024)0650. The base map is sourced from China's National Geographic Information Public Service Platform-Tianditu, and the boundaries have not been modified.

The specific steps of the household survey are as follows: First, the investigators communicated with the staff of the sample village to obtain a list of permanent residents to determine the sampling frame. Second, the farmers in the sampling frame were numbered (e.g., 1, 2, 3,. . ., 100). Using a computer for random sampling, we entered the formula "=INT(RAND()×(100 − 1 + 1)) + 1" in Excel to generate random numbers as the identifiers for the selected farmers, with 8 samples drawn from each sample village. Next, based on the sampling results, we identified the sample farmers and conducted household interviews, selecting household heads or individuals familiar with the family situation as respondents. After the questionnaire was completed, it was checked to prevent errors and omissions. Upon completion of the survey, we assessed the representativeness of the sample farmers, considering factors such as income structure, family structure, and production structure. When the farmers' information closely matched the actual situation in the village, it was determined to be valid data, which was then coded and stored. If 6–8 valid samples could be obtained from the selected 8 farmers, the survey was concluded. If not, supplementary sampling was initiated with the help of the computer until a sufficient amount of valid data were acquired.

The ratio of men to women in this survey is equal, and most farmers' livelihoods typically consist of 3–5 persons. The basic characteristics of the sample farmers' livelihoods are shown in Table 1. The basic data for the county economy subsystem are mainly sourced from the 2021 Shaanxi Statistical Yearbook and the Statistical Yearbooks of various cities [52]. Missing data were primarily obtained through consulting the Statistical Bulletin of various districts and counties. The descriptive statistics of county data are shown in Table 2.

Table 1. Basic characteristics of sample farmers' livelihoods.

Indicator	Category	Frequency Number	Frequency Rate
Gender	Male	247	54.77%
	Female	204	45.23%
Age groups	≤20 years old	37	8.20%
	21–65 years old	377	83.60%
	≥66 years old	37	8.20%
Education level	Junior high school and below	311	68.96%
	High school or Technical Secondary School	63	13.97%
	College and Above	77	17.07%
Population size	≤2 people	29	6.43%
	3–5 people	283	84.92%
	≥5 people	39	8.65%
Region	Hanzhong	143	31.71%
	Ankang	180	39.91%
	Shangluo	128	28.38%

Table 2. Descriptive statistics of county variables.

Variable Name	Minimum	Maximum	Mean	Standard Deviation
Resident population (10,000 people)	2.66	89.49	27.70	18.88
Area (km^2)	556.00	3678.00	2515.00	841.62
Number of students in primary and middle schools (people)	2717.00	126,177.00	35,464.57	24,786.12
Number of beds in medical institutions (beds)	161.00	7388.00	2049.29	1778.92
Total grain output (tons)	9417.00	192,816.00	84,811.50	50,674.17
Area of facility agriculture (hectares)	6.00	746.00	208.50	172.31
Annual hours of sunshine (hours)	1364.90	2737.40	2216.67	406.94
Annual precipitation (millimeters)	613.70	1233.30	862.21	160.30
Regional public fiscal revenue (10,000 CNY)	3311.00	116,309.00	23,409.11	23,974.18
Urbanization rate (%)	38.60	74.30	47.77	6.27
Number of legal entities (units)	809.00	16,865.00	3913.50	3297.70
Number of landline users (households)	2515.00	171,046.00	28,429.44	30,815.04
Regional gross domestic product (10,000 CNY)	118,813.00	3,758,179.00	1,222,004.29	919,901.77
Per capita disposable income of all residents (CNY)	15,022.00	28,717.00	18,907.25	2632.03
Regional public fiscal expenditure (10,000 CNY)	93,233.00	724,265.00	315,441.11	124,442.80

Two points need to be clarified here. First, although the research year of this paper is 2020, according to the publication conventions of the National Bureau of Statistics of China, along with provincial and municipal statistical bureaus, the 2021 statistical yearbook actually reflects data for 2020. Therefore, we consulted the relevant 2021 statistical yearbooks. Second, based on our team's actual visits in the southern Shaanxi Qinba mountains area and the report titled '2020: A Record of Shaanxi's Fight Against COVID-19' [53], the effectiveness of combating COVID-19 in the southern Shaanxi Qinba Mountain area in 2020 was significant. The districts and counties were generally functioning under normal production and living orders, and the impact of the pandemic on farmers' livelihoods and county-level economic development was relatively minor. Thus, this paper does not discuss the impact of the pandemic on data collection and research results.

2.3. Variable Selection and Coupling Mechanism

(1) Evaluation Index System for Farmers' livelihood efficiency

Based on the sustainable livelihood analysis framework [54] and actual survey conditions, this paper divides farmers' livelihood capital into 5 dimensions with 16 indicators.

The output factors include 5 indicators, such as income level and other related metrics. The specific variables and their weights are shown in Table 3.

Table 3. Evaluation index system of farmers' livelihood efficiency.

Primary Indicator	Secondary Indicator (Weight)	Tertiary Indicator	Indicator Description	Weight
Farmers' livelihood capital	Farmers' human capital (0.194)	Education level	1: Primary school and below; 2: Junior high school; 3: High school or vocational school; 4: College and above	0.813
		Health status	1: Very poor; 2: Poor; 3: Average; 4: Good; 5: Excellent	0.061
		Population size	Number of family members (persons)	0.126
	Farmers' physical capital (0.156)	Number of livestock	Number of livestock (heads)	0.844
		Living materials	Number of living materials (items)	0.034
		Transportation vehicles	Number of transportation vehicles (units)	0.121
	Farmers' natural capital (0.214)	Agricultural production area	Total planting and breeding area (hectares)	0.706
		Housing area	Housing area (m^2)	0.294
	Farmers' financial capital (0.286)	Annual total income	Annual total household income (CNY)	0.139
		Loan/borrowing channels	Number of loan/borrowing channels (types)	0.284
		Loan/borrowing purposes	Number of loan/borrowing purposes (types)	0.577
	Farmers' social capital (0.150)	Family social work situation	Number of family social work participations (instances)	0.609
		Trust in surrounding villagers	1: Almost none; 2: Few; 3: Half; 4: Majority; 5: Almost all	0.029
		Assistance channels during livelihood difficulties	Number of assistance channels during livelihood difficulties (types)	0.099
		Information tools	Number of information tools (types)	0.072
		Information channels	Number of information channels (types)	0.192
Farmers' livelihood output	Income level	Improvement in income level	1: Significantly decreased; 2: Decreased; 3: No change; 4: Increased; 5: Significantly increased	0.253
	Education and healthcare level	Improvement in education and healthcare		0.062
	Employment opportunities	Improvement in employment channels		0.367
	Rural attachment	Improvement in pride and attachment to hometown		0.184
	Ecological conservation awareness	Improvement in ecological conservation awareness and values		0.134

Note: The weights for each indicator were calculated using the entropy method after normalizing the raw data, consistent with Table 4.

Table 4. Evaluation index system of county livelihood efficiency.

Primary Indicator	Secondary Indicator (Weight)	Tertiary Indicator	Indicator Description (Unit)	Weight
County livelihood capital	County human capital (0.127)	Population density	Resident population/Area (persons/km^2)	0.694
		Education status	Number of primary and secondary school students per 10,000 people (persons)	0.108
		Healthcare status	Number of hospital beds per 10,000 people (beds)	0.198

Table 4. *Cont.*

Primary Indicator	Secondary Indicator (Weight)	Tertiary Indicator	Indicator Description (Unit)	Weight
County livelihood output	County physical capital (0.175)	Grain output	Total grain output (tons)	0.337
		Fixed assets	Fixed asset investment (10,000 CNY)	0.225
		Facility agriculture	Facility agriculture land area (hm^2)	0.438
	County natural capital (0.087)	Sunshine condition	Annual sunshine hours (hours)	0.407
		Precipitation condition	Annual precipitation (mm)	0.217
		Cultivated land area	Cultivated land area (hm^2)	0.376
	County financial capital (0.397)	Residents' savings	Balance of residents' savings deposits (10,000 CNY)	0.266
		Institutional loans	Year-end balance of loans from financial institutions (10,000 CNY)	0.423
		Fiscal revenue	Regional public fiscal revenue (10,000 CNY)	0.311
	County social capital (0.214)	Urbanization rate	Urban resident population/Total resident population (%)	0.153
		Social organizations	Number of legal entities (units)	0.404
		Social welfare	Number of beds in social work institutions per 10,000 people (beds)	0.332
		External communication	Number of fixed telephone users per 10,000 people (households)	0.111
	Economic development level	County GDP	County GDP (10,000 CNY)	0.272
	Income level	County income	Total county income (10,000 CNY)	0.304
	Consumption level	County consumption	Total retail sales of consumer goods (10,000 CNY)	0.423

Farmers' human capital refers to the aggregate of knowledge, skills, health, and labor force of household members [55]. Educational level influences farmers' production efficiency and non-agricultural employment capabilities to some extent [56]. Health status directly impacts the labor capacity and quality of life of farmers [57]. The number of family members reflects the labor force scale, which has a significant impact on the stability of the livelihood system. Therefore, educational level, health status, and number of family members are selected to represent farmers' human capital.

Farmers' physical capital refers to the basic material conditions for agricultural production and living [58]. Engaging in livestock farming can provide farmers with a stable source of income and enhance their resilience to risks [59]. The abundance of living materials contributes to enhancing life satisfaction. The prevalence of transportation vehicles reflects logistics efficiency and market access ability, which is of significant importance for expanding the scope of livelihoods [60]. Therefore, the number of livestock, living materials, and transportation vehicles is selected to represent farmers' physical capital.

Farmers' natural capital refers to the natural resources available for farmers to utilize, including water sources, arable land, and other forms of land use [61]. Among these, the area of agricultural production is a key indicator of the scale of farmers' production, providing basic security for sustainable production [62]. The area of housing reflects the quality of farmers' lives to some extent, and high-quality living conditions contribute to an increased attachment to rural areas [63]. Therefore, the area of agricultural production and the area of housing are selected to represent farmers' natural capital.

Farmers' financial capital includes cash, loans, and borrowings used for production and consumption [64]. Annual total income supports basic living needs and non-agricultural investments. The diversity of loan and borrowing channels relates to a farmer's ability to access external funding. The variety in the purposes of loans and borrowings reflects the diversity in farmers' use of funds and investment decisions [65]. Therefore, this

paper selects annual total income, loan and borrowing channels, and the purposes of loans and borrowings to represent farmers' financial capital.

Farmers' social capital encompasses resources within social networks, mutual assistance, and information sharing [66]. The family's social work situation reflects the activity within social networks and their ability to participate in social activities [67]. Trust in surrounding villagers is the foundation for cooperation and sharing [68]. The channels of assistance during livelihood difficulties reflect the extent of external support farmers can obtain. The number of information tools and channels relates to farmers' ability to acquire and process information [69]. Therefore, the family's social work situation, trust in surrounding villagers, channels of assistance, as well as information channels and information tools, are selected to represent farmers' social capital.

Farmers' livelihood outputs refer to the economic income and co-benefits that farmers achieve through the utilization and management of various capitals. Based on relevant studies [2,4], this paper selects disposable income, improvements in education and healthcare conditions, increased employment opportunities and structural optimization, rural attachment, and farmers' ecological awareness as the variables representing farmers' livelihood outputs. Among these, disposable income is a key indicator of the economic status of farmers' livelihoods. Improvements in education and healthcare conditions are crucial for enhancing basic living security [70]. The increase in employment opportunities and optimization of employment structures contribute to raising farmers' incomes [71]. The enhancement of farmers' pride and attachment to their hometown reflects their recognition of rural culture [72]. Farmers' awareness of ecological protection increases, contributing to environmental conservation and sustainable livelihoods [73].

(2) Evaluation Index System for County Livelihood Efficiency

In order to scientifically calculate the county livelihood efficiency, based on the definition of "livelihood efficiency" and the principle of data availability at the county level, this paper selects 16 indicators, such as population density and educational resources, as the input indicators for county livelihood resources and 3 indicators, including economic development level, income level, and consumption level, as the livelihood outputs. The evaluation index system is shown in Table 4.

County human capital refers to the stock of knowledge, skills, health status, and creativity possessed by all individuals within a specific county [74]. Population density is a crucial indicator of regional population distribution. Abundance of educational resources helps improve labor productivity [75]. The balanced distribution of medical resources enhances individuals' productivity and sense of security [76]. Therefore, population density, the number of students per 10,000 people in primary and secondary schools, and the number of hospital beds are selected to represent county human capital.

County physical capital refers to the material conditions that sustain the livelihood of residents within a specific county [45]. Grain output reflects a region's material production capacity and its ability to sustain its population [77]. Investment in fixed assets is crucial for improving public infrastructure. Facility agriculture concretely embodies agricultural modernization and represents an inevitable trend [78]. Therefore, the total grain output, the amount of investment in fixed assets, and the area occupied by facility agriculture are selected to represent the material capital of the county.

County natural capital includes all the natural resources that exist within the boundaries of a particular county, forming the basis of livelihoods and the production of local people [79]. Land and climate are the fundamental conditions for agricultural production. It is estimated that about 800 million people worldwide face long-term food insecurity due to climate change, natural disasters, and pests [80]. Therefore, sunshine, precipitation, and arable land area were selected to represent the natural capital of the county.

County financial capital refers to the fiscal and financial conditions that support county development [45]. The balance of savings deposits reflects the amount of financial capital in the county [81]. Regional fiscal revenue is the income obtained by the region through participation in the distribution of social products. The balance of loans from financial

institutions reflects how banks utilize their funds [82]. Therefore, the balance of residents' savings deposits, the year-end balance of loans from financial institutions, and the regional fiscal revenue are selected to represent the county's financial capital.

County social capital refers to the social resources that support the achievement of livelihood goals within the county [83]. Urbanization is a key indicator of modernization. Social institutions not only maintain social stability but also facilitate the sharing of economic development outcomes among the people [84]. External communication reflects the level of information accessibility in modern towns [85]. Therefore, the urbanization rate, the number of legal entities, the number of social work institution beds, and the number of fixed-line telephone users were selected to represent the county's social capital.

County livelihood output refers to how well livelihood goals are met within the county. Previous studies suggest that pastoralists' livelihood outputs include income levels, living standards, welfare levels, entertainment richness, and happiness [2]. This study measures county livelihood outputs based on three aspects, namely, gross regional product, total regional income, and total retail sales of consumer goods. Specifically, GDP and regional income reflect the economic status of the county. Increased county consumption can extend industrial chains and improve resource allocation, resulting in various co-benefits for social development [86].

Coupling Mechanism between Farmers' Livelihood Systems and County Livelihood Systems

Farmers' livelihoods and county livelihoods are interdependent and closely interconnected in overall development [1,46]. This study uses the sustainable livelihoods framework and integrates resource dependence theory [54,87] to explain the mechanisms of resource flow and dependence between different systems. With the continuous promotion of agricultural modernization and talent cultivation, human resources are increasingly becoming the primary resource driving socioeconomic development. Studies have shown that the accumulation and optimization of human capital not only influence farmers' livelihood strategies [88] but also directly or indirectly promote regional economic growth [89]. The effective utilization and upgrading of physical capital provide a solid foundation for farmers' livelihoods and agricultural development [90]. The protection and sustainable management of natural capital are not only social responsibilities and obligations of households [91] but also ecological guarantees for the long-term stable operation of county livelihood systems [92]. Innovative financial products can support households [93] and facilitate high-quality agricultural development in the county [94]. The ongoing development of social networks strengthens social capital, enhances the connection between farmers and the county, and promotes the effective integration of resources [95]. Therefore, this paper explores the coupling mechanism between farmers' livelihood systems and county livelihood systems from five aspects, namely, human capital, physical capital, natural capital, financial capital, and social capital, as shown in Figure 2.

Human capital is the core of interaction between farmers' livelihood systems and county livelihood systems. The enhancement of household labor quality can boost county productivity, driving regional industrial upgrading and optimization [96]. Meanwhile, improvements in education and healthcare at the county level ensure farmers' welfare, further enhancing the stability and adaptability of their livelihoods [97].

Physical capital serves as the foundation for resource sharing between farmers' livelihood systems and county livelihood systems. According to capital accumulation theory [98], enhancing farmers' material conditions will gradually drive county economic growth. Meanwhile, the improvement in county infrastructure provides strong support for farmers' production, enabling more efficient livelihood activities [99].

Natural capital guarantees mutual development between farmers' livelihood systems and county livelihood systems. The rational utilization of natural resources by farmers not only optimizes their own livelihood structures but also promotes county agricultural output and ecosystem balance [100]. Furthermore, ecological improvements and disaster prevention at the county level reduce the livelihood risks faced by farmers, further enhancing their resilience [101].

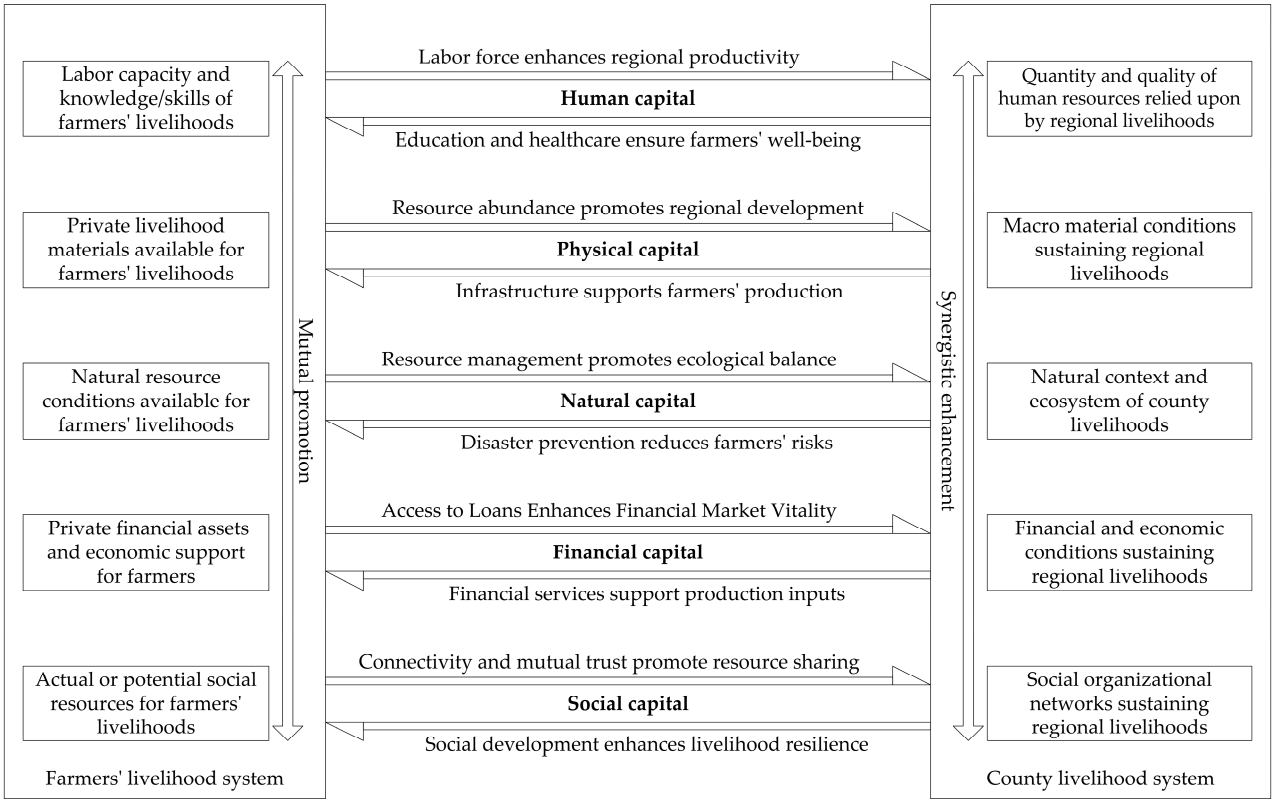


Figure 2. Coupling mechanism between farmers' and county livelihood systems.

Financial capital acts as the bond for coordinated operation between farmers' livelihood systems and county livelihood systems. Prudent wealth management and access to loans by farmers can enhance the activity of the county financial market and improve regional welfare levels [102]. At the same time, county financial services and fiscal support provide farmers with necessary financial guarantees, facilitating technological improvements and market expansion [103].

Social capital serves as the bridge for a close connection between farmers' livelihood systems and county livelihood systems. According to social network theory [104], farmers achieve livelihood interaction through establishing social relationships, promoting the accumulation and sharing of county livelihood capital [30]. The social capital at the county level ensures farmers' productivity, enhancing their capacity to cope with livelihood challenges [105].

2.4. Research Methods

2.4.1. System Dynamics

System dynamics is a powerful methodology that integrates cybernetics, systems theory, information science, and tactical decision-making. This methodology emphasizes perspectives such as system, wholeness, development, and motion, enabling cross-space and cross-time interactions of systems and strategies, making it well-suited for cross-scale coupled system modeling problems [106]. In this paper, with the help of Vensim PLE 7.3.5, we constructed causal loop diagrams and system flow diagrams to illustrate the livelihood efficiency of farmers and counties in the Qinba mountains area of southern Shaanxi Province. The model's reasonableness is demonstrated through historical tests and system stability via simulations and adjustments to the simulation step size. Once the model's rationality is confirmed, scenario regulation simulations for multi-scale livelihood efficiency coupling and coordination can be conducted by adjusting parameters. This allows comparison of coupling and coordination levels under different regulation modes, providing a theoretical basis and empirical reference for policy implementation.

2.4.2. Data Envelopment Analysis (DEA)

The data envelopment analysis (DEA) method can analyze the complex production function with multiple inputs and outputs. In designing the livelihood efficiency evaluation framework, this study follows relevant aspects of sustainable livelihood theory and previous research. It measures livelihood inputs across five dimensions, including human capital and physical capital, among others, and considers livelihood outputs in terms of economic value as well as their co-benefits, as illustrated in Figure 3.

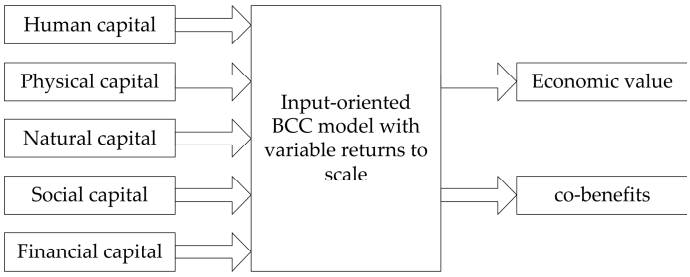


Figure 3. Schematic diagram of the livelihood efficiency evaluation framework.

According to Figure 3, when calculating livelihood efficiency at various scales, it is essential to fully consider the actual development conditions and data availability. Given the rich connotation of livelihood activities, the measurement of efficiency must incorporate multiple input and output indicators that align with the application conditions of the data envelopment analysis (DEA) model. Therefore, referencing the measurement of livelihood efficiency by Su Fang et al. [107], we choose the input-oriented BCC model with variable returns to scale to calculate farmers' and county livelihood efficiency. The formula for the calculation is as follows:

$$\begin{cases} min[\theta_i - (\sum_{j=1}^{m} S_j^- + \sum_{r=1}^{s} S_r^+)] \\ s.t. \sum_{i=1}^{n} x_{ij}\lambda_i + S_j^+ = \theta_i x_{ij} \\ \sum_{i=1}^{n} y_{ir}\lambda_i - S_r^+ = \theta_i y_{ir} \\ \sum_{i=1}^{n} \lambda_i = 1 \\ \lambda_i, \theta_i, S_j^-, S_r^+ \geq 0 \end{cases} \quad (1)$$

In Equation (1), x_{ij} represents the j-th livelihood input of the i-th decision-making unit, and y_{ir} represents the r-th livelihood output of the i-th decision-making unit. S_j^- is the slack variable for livelihood input, S_r^+ is the surplus variable for livelihood output, and λ_i is the weight variable. ε is a non-Archimedean infinitesimal.

2.4.3. Coupling Coordination Degree

The coupling coordination model is often used to assess the interrelationships between different systems and the degree of their coordinated development and has been widely applied in various fields, including ecology, economics, and social sciences. In this paper, "coupling" specifically refers to the interactions between farmers' livelihood systems and county livelihood systems, emphasizing the interconnections and joint roles of these two scales of livelihood efficiency. "Coordination" means that these two systems can effectively adjust and optimize their respective resource allocation and strategies to achieve sustainable livelihood development, maximizing overall benefits through interactive and symbiotic relationships. Ideally, farmers' livelihood efficiency and county livelihood efficiency should complement and support each other, forming a synergy to achieve common goals. Therefore, the "coupling coordination degree" serves as a comprehensive indicator to measure the mutually reinforcing and coordinated development relationship between farmers and county livelihood systems, calculated as follows:

$$C = 2 \times \left[\frac{u_1 \times u_2}{(u_1 + u_2)} \right]^{\frac{1}{2}} \quad (2)$$

$$T = \alpha u_1 + \beta u_2 \quad (3)$$

$$D(u_1, u_2) = \sqrt{C \times T} \quad (4)$$

In Equations (2)–(4), C denotes the coupling degree, reflecting the quality of the coupled development between the two systems; T represents the development degree, indicating the overall efficiency or level of the two systems; D signifies the coupling coordination degree, reflecting the extent of coordinated development between the two systems. Here, u_1 stands for farmers' livelihood efficiency, u_2 represents county livelihood efficiency, and α and β are the weights. Considering the equal importance of farmers and county livelihood efficiencies in the development process, both α and β are set to 0.5.

2.5. Construction of a Multi-Scale Livelihood Efficiency Complex System

2.5.1. Determination of System Boundaries

This study primarily focuses on the subsystems of farmers and counties to construct a coupled system of farmers' livelihood efficiencies and county livelihood efficiencies. The spatial boundary of the model is the Qinba mountains area in southern Shaanxi, with the cross-sectional year being 2020. Due to the many influencing factors involved in the system, in order to highlight the object of study and the purpose of modeling, it is assumed that the living conditions of farmers and the macro-development environment are stable, with no significant natural disasters, economic fluctuations, or policy changes.

2.5.2. Causal Relationship Analysis

There are many complex causal feedbacks between farmers' livelihood efficiency and county livelihood efficiency (Figure 4). The main causal feedback loops include the following:

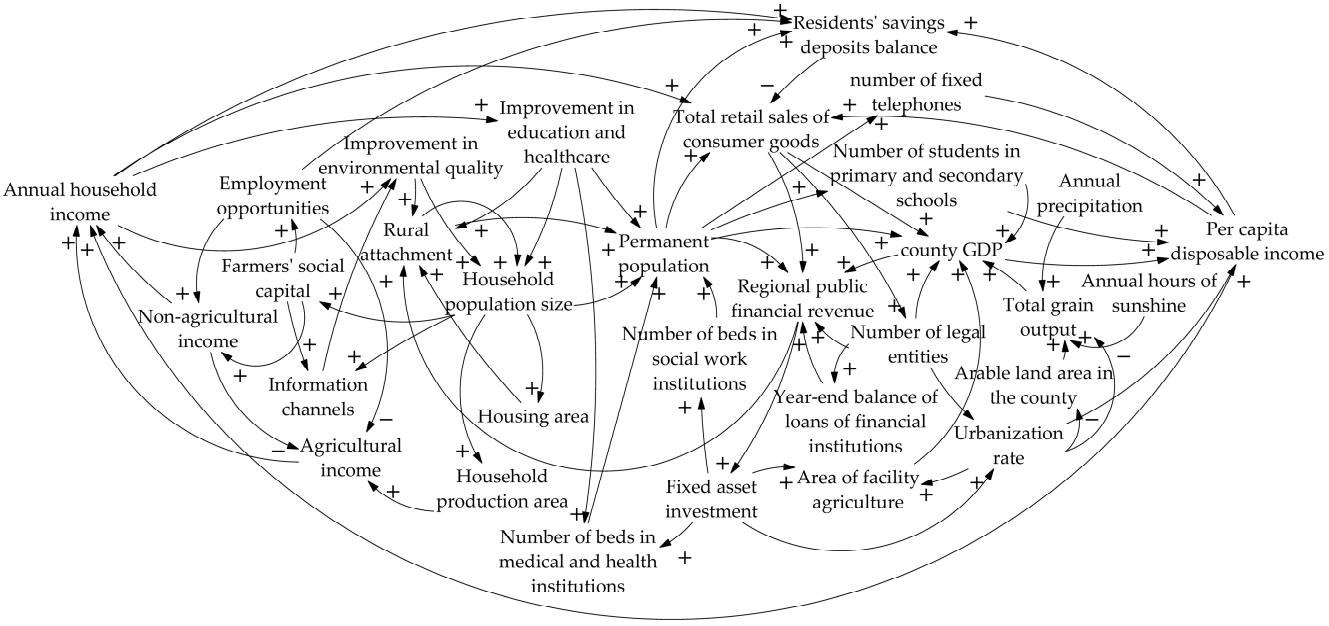


Figure 4. A causal relationship diagram of the coupled system between farmers' and county livelihood efficiencies.

(1) Annual household income →+ improvement in education and healthcare →+ rural attachment →+ resident population →+ residents' savings deposits →+ total volume of social consumer goods →+ regional gross domestic product (GDP) →+ regional

public fiscal revenue →+ fixed asset investment →+ urbanization rate →+ per capita disposable income →+ annual household income.

(2) Household population size →+ resident population →+ number of students in primary and secondary schools →+ regional GDP →+ per capita disposable income →+ residents' savings deposits →+ total retail sales of consumer goods →+ number of legal entities →+ year-end balance of loans from financial institutions →+ regional public fiscal revenue →+ rural attachment →+ household population size.

(3) Per capita disposable income →+ residents' savings deposits →+ total retail sales of consumer goods →+ regional GDP →+ regional public fiscal revenue →+ fixed asset investment →+ number of hospital beds per ten thousand people →+ resident population →+ number of fixed telephones per ten thousand people →+ per capita disposable income.

(4) Urbanization rate →− arable land area →+ total grain output →+ regional GDP →+ per capita disposable income →+ balance of residents' savings deposits →+ total retail sales of consumer goods →+ number of legal entities →+ urbanization rate.

In Figure 4 and the 4 causal loops above, "a →+ b" indicates that an increase in factor a leads to an increase in factor b. For example, "improvement in education and healthcare →+ rural attachment" shows that better education and healthcare enhance farmers' attachment to their rural communities. Conversely, "c →− d" indicates that an increase in factor c will result in a decrease in factor d. For instance, "urbanization rate →− arable land area " suggests that as the urbanization rate increases, arable land area decreases.

2.5.3. Establishment of System Flow Diagrams

Based on causal loop analysis, this study constructs a coupled system dynamics model of farmers' and county livelihood efficiencies with the stock-flow diagram presented in Figure 5. The main variables in the model design include the following: (1) State variables, which encompass net household income, the number of household members, and county cultivated land area. (2) Rate variables, which include total household income, total household expenditure, increase in household population, decrease in household population, and increase in cultivated land. (3) Auxiliary variables, which mainly include residents' savings deposits, non-farm income, and per capita arable land. (4) Constants, which mainly include the area of the region, annual precipitation, annual sunshine hours, etc.

In Figure 5, the black font represents the main variables, while the gray font indicates shadow variables. Shadow variables act as "projections" of their corresponding main variables; they are logically the same and are intended to reduce the crossing of arrows in the diagram, thereby enhancing clarity and readability. The box variables represent state variables, such as the area of cropland in the county. Arrows with funnels represent rate variables, indicating the speed of change in certain quantities in the system, such as the increase in cultivated land and how stock changes over time. Circle variables represent subsistence capital, such as county natural capital, while hexagons variables represent subsistence output, such as county income. A single arrow from one variable (called a) to another variable (called b) shows a direct effect of a on b. For example, an arrow from the area of a farmer's cultivated land to the area of cash crops indicates that changes in cultivated land directly affect cash crop area. If farmers have more arable land, they may choose to grow more cash crops, and vice versa.

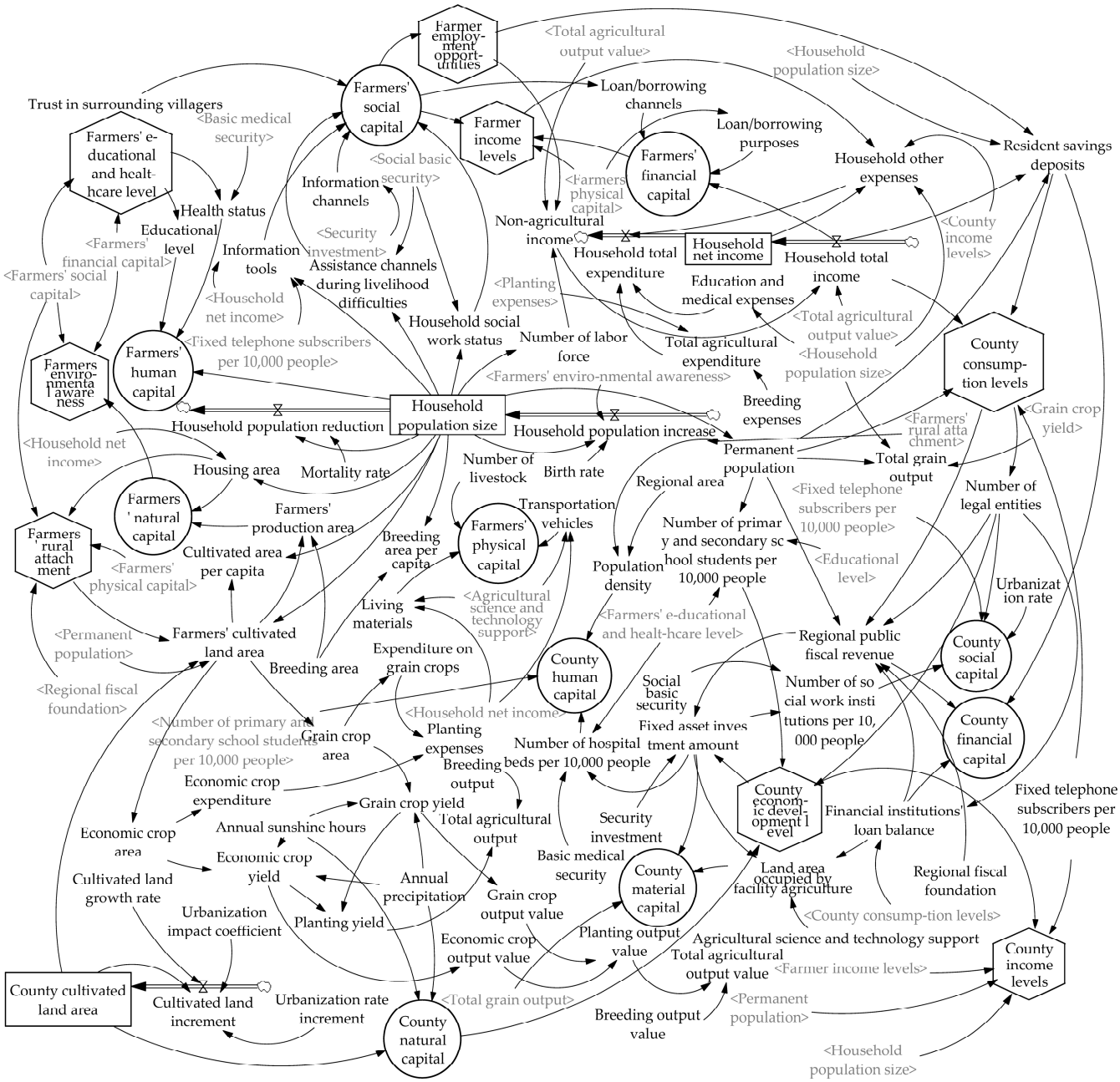


Figure 5. Farmers' and county livelihood efficiency coupled system flow diagram.

2.5.4. Design of Model Equations

Based on the interrelations and operational principles among variables within the system model, this study, after organizing field survey data at the farmers' level and statistical data at the county level in the Qinba mountains area of southern Shaanxi, combined methods such as the entropy method, arithmetic mean method, and comprehensive evaluation method, conducted parameter estimation and model equation derivation. Following continuous debugging and system operation, a coupled system dynamics model of livelihood efficiency for farmers and counties was established. The relevant parameters primarily originate from statistical materials and field survey data. Due to limited space, only a few representative equations are listed here as follows:

(1) Household net income = INTEG (Total household income − Total household expenses, 28,895.8).

(2) Household population size = INTEG (Increase in household population − Decrease in household population, 3.97).
(3) County arable land area = INTEG (Increase in arable land, 450,987).
(4) Farmer's human capital = Health status × 0.061 + Education level × 0.813 + Household population size × 0.126.
(5) Farmer's physical capital = Number of livestock × 0.844 + Transportation vehicles × 0.121 + Living materials × 0.034.
(6) County social capital = Urbanization rate × 0.178 + Number of fixed telephones per 10,000 people × 0.144 + Number of social work institution beds per 10,000 people × 0.301 + Number of legal entities × 0.376.

Equations (1) to (3) describe how some key variables in the system (household net income, household population, and county arable land area) evolve dynamically over time through their respective rates of change (such as income, expenditure, population increase and decrease, and increase in arable land). For instance, Equation (1) indicates that household net income is the cumulative result of total household income minus total household expenditure, meaning that as time progresses, household net income changes by continuously accumulating the difference between income and expenditure. Equations (4) to (6) represent various forms of livelihood capital for farmers or counties, calculated by summing the components according to specific weights to obtain the total capital value. For example, Equation (4) indicates that farmers' human capital is influenced by three factors as follows: health status, education level, and household population. Among these, education level has the greatest contribution to human capital with a weight of 0.813, indicating that education plays an important role in enhancing human capital.

2.5.5. Model Validation

To ensure the model's validity, we conduct various tests, including intuitive, operational, stability, and historical tests. Among these, the stability test is conducted by changing the model's step size and observing the consistency in the trend of data changes [108]. We select eight variables, namely, regional public fiscal revenue, grain crop expenditure, total household expenses, facility agriculture area, ecological protection awareness, county arable land area, county consumption level, and rural attachment, and examine the outputs of each variable over periods of 3 months, 6 months, and 12 months. The test results are shown in Figure 6. The historical test compares the deviation of simulated values with historical values to assess if the system reflects development patterns [109]. In this study, ten indicators, including total household income and non-agricultural income, are selected as test variables. Systematic errors between simulated and actual values from simulation runs are shown in Table 5.

As shown in Figure 6, the simulation results for each variable at four time steps (3 months, 6 months, 9 months, and 12 months) exhibit the same trend, indicating model stability. It should be noted that the data on farmers are based on only one year's research results. Therefore, the model constructed in this paper is used solely to analyze the changes in farmers' livelihood efficiency, county livelihood efficiency, and their coupling coordination degree in different scenarios for the year 2020, without considering the cumulative impact of time factors on the system. Consequently, the trends of the variables over time under different simulation steps are only applicable for proving the system's stability from the perspective of trend consistency. They are not suitable for predicting the future trends of the variables over time. As shown in Table 5, the absolute error between the simulated and historical values of each variable obtained from the system operation is less than 2.3%. This indicates high fitting accuracy and that the model essentially reflects the operation of the real system. In summary, the model effectively reflects the real system and its simulations.

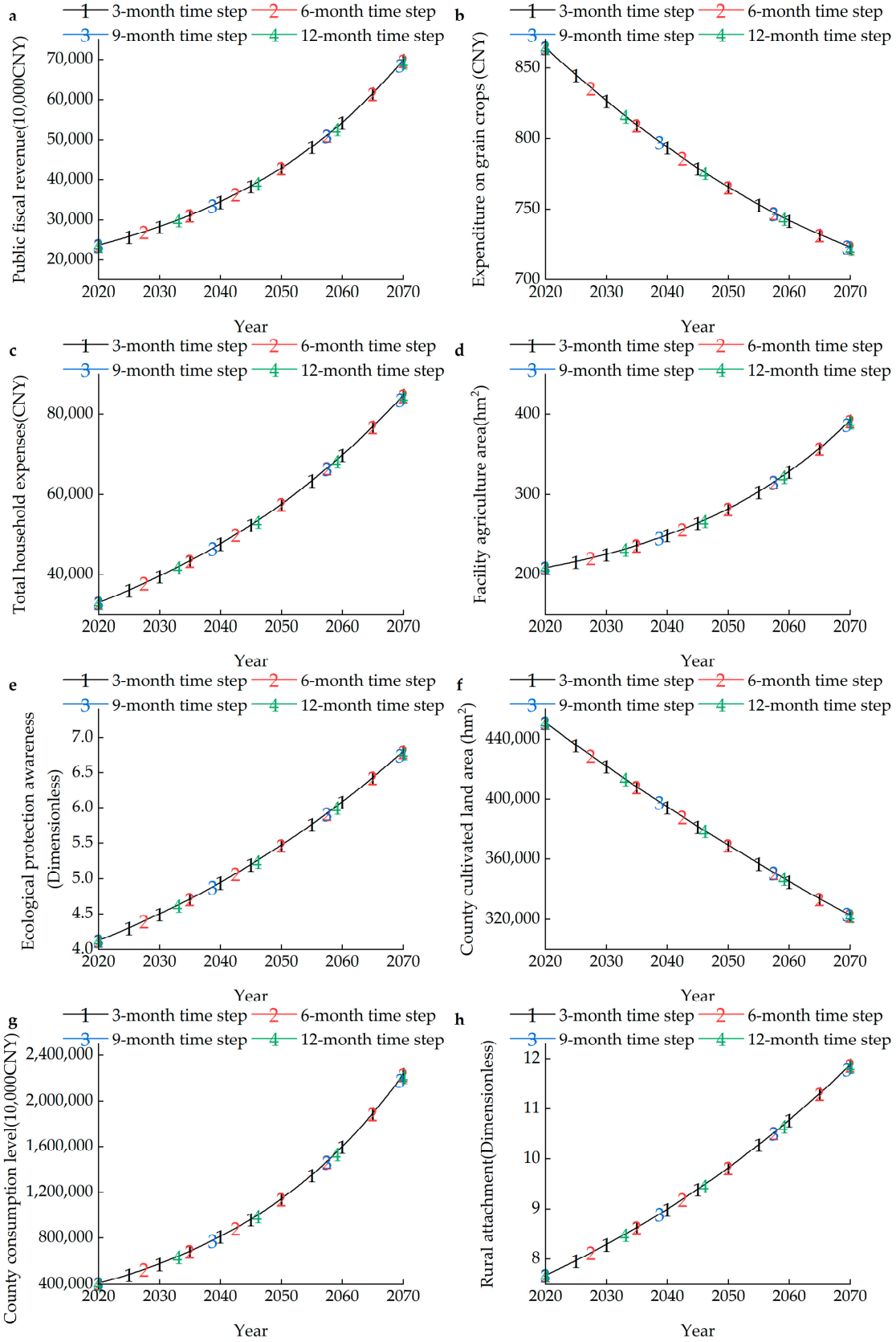


Figure 6. Simulation results at different time steps. Note: Subfigures (**a**–**h**) represent the changes in simulation results for eight variables under the step size test, namely, regional public fiscal revenue, expenditure on grain crop, total household expenditure, facility agriculture area, ecological protection awareness, county cultivated land area, county consumption level, and rural attachment, respectively.

Table 5. Historical test results of selected variables.

Indicators (Unit)	Actual Value	Simulated Value	Error Value (%)
Total household income (CNY)	61,824.28	61,728.20	−0.16
Non-agricultural income (CNY)	54,106.73	54,002.30	−0.19
Agricultural production area (m^2)	2007.77	2033.44	1.29
Number of labor force (persons)	3.15	3.22	2.11
Household social work status (units)	0.61	0.62	0.28
Balance of residents' savings deposits (10,000 CNY)	1,460,069.57	1,432,130.00	−1.91
Facility agriculture land area (hm^2)	208.50	208.68	−0.09
Fixed asset investment (10,000 CNY)	1,401,814.97	140,579.00	0.28
Number of legal entities (units)	3913.50	4002.64	2.28
Regional public fiscal revenue (10,000 CNY)	23,409.11	23,662.50	1.08

Note: The actual values of the indicators are sourced from publicly available publications such as the Shaanxi Statistical Yearbook (see Section 2.2, Data Sources for details). The simulated values are derived from simulations based on the system constructed in this paper, using the Vensim PLE 7.3.5 to compute values according to the established logical relationships.

3. Results

3.1. Analysis of Current Situation of Coupling Coordination of Farmers' Livelihood Efficiency and County Livelihood Efficiency in the Qinba Mountains Area of Southern Shaanxi

The farmers' survey results were matched with county data, followed by standardization of the data rows. Using the entropy method, livelihood input and output data at both the farmers' and county levels were obtained for 24 counties in the Qinba mountains area of southern Shaanxi (data from four counties, including Liuba, were missing). The DEA model was employed to calculate the livelihood efficiency at both the household and county levels. Subsequently, the coupling coordination degree model was used to determine the coupling coordination degree of farmers' and county livelihood efficiencies for each county in 2020. Referring to previous research [110], the coupling coordination degree was classified into 5 levels, as shown in Figure 7.

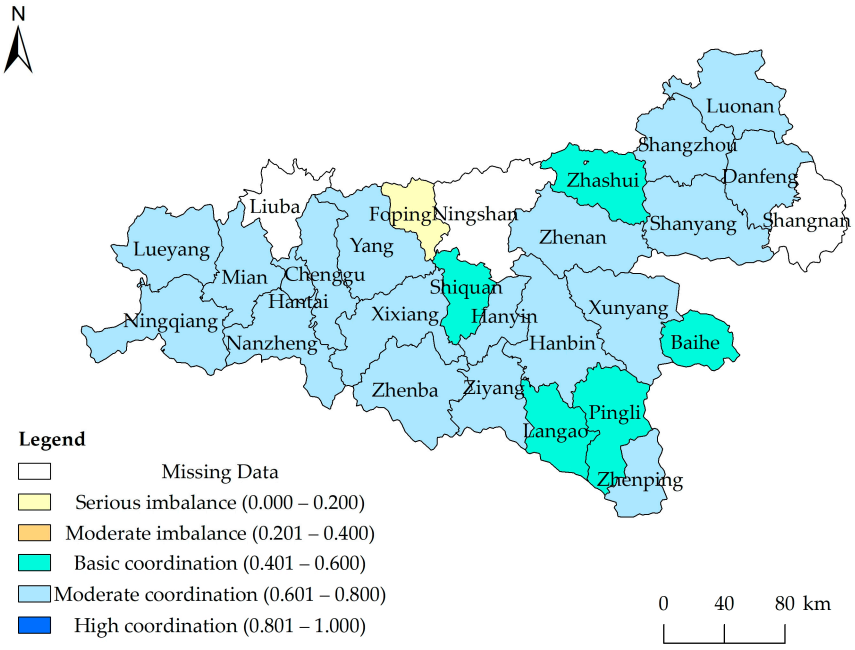


Figure 7. Spatial variation of coupling coordination degree between farmers' and county livelihood efficiency in the Qinba mountains area of southern Shaanxi. Note: The source of the base map and the review number are consistent with Figure 1.

According to the measurement results, the following data can be observed:

(1) The overall situation of the coupling coordination of farmers' livelihood efficiency and county livelihood efficiency in the Qinba mountains area of southern Shaanxi. The average value of the coupling coordination degree of farmers' livelihood efficiency and county livelihood efficiency in the Qinba mountains area of southern Shaanxi is 0.623, which is at a moderate coordination. This indicates that the activities of farmers and the overall development of the county are mutually reinforcing. However, there is still room for improvement, and during the rural revitalization phase, this relationship holds significant representational value and research significance. At present, there is still a considerable distance for the Qinba mountains area to achieve a high level of coordination. This indicates that there are still mismatched or uncoordinated aspects between the livelihoods of farmers and county development. This may be due to factors such as uneven distribution of resources, inadequate implementation of policies, or an irrational industrial structure.

(2) The coupling coordination between farmers' livelihood efficiency and county livelihood efficiency in the Qinba mountains area of southern Shaanxi is ranked as follows: Hanzhong > Ankang > Shangluo. The average coupling coordination degree between farmers' livelihood efficiency and county livelihood efficiency in Hanzhong is 0.671, which indicates moderate coordination. The average coupling coordination degree in Ankang is 0.631, also indicating moderate coordination. Meanwhile, in Shangluo, the average degree is 0.572, which indicates basic coordination. Based on the calculation results, although farmers' livelihood efficiency and the county livelihood capital in the three cities are relatively similar, the livelihood output level in Hanzhong is significantly higher than that in Ankang and Shangluo. The main reason is that Hanzhong has relatively better locational conditions. As a regional central city [111], Hanzhong is located at the junction of the Guanzhong Plain Urban Agglomeration and the Chengdu-Chongqing Economic Circle. It is also at the intersection of four major national strategies, namely, the Yangtze River Economic Belt, the Yellow River Basin Ecological Protection and High-Quality Development, the Chengdu-Chongqing Twin City Economic Circle, and the Han River Ecological Economic Belt [112]. With this geographical advantage, Hanzhong has actively developed trade and industries such as the traditional Chinese medicine warehousing and distribution center, gradually occupying the optimal niche for development in the Qinba mountains area of southern Shaanxi [113]. Overall, Hanzhong already possesses a high level of economic development, infrastructure, human capital, and information technology construction, and its superior locational conditions further facilitate the synergistic improvement in multi-scale livelihood efficiency.

(3) In the Qinba mountains area of southern Shaanxi, the coordination between farmers' livelihood efficiency and the county's livelihood efficiency is as follows: The coupling coordination degree of Foping is less than 0.200, indicating a state of serious imbalance. For 5 counties, including Shiquan, Zhashui, Baihe, Lan'gao, and Pingli, the degree is between 0.401 and 0.600, indicating a state of basic coordination. For 19 counties, including Lueyang, Ningqiang, and Yang, etc., the degree is between 0.601 and 0.800, reflecting a state of moderate coordination. Specifically, in Foping, due to inconvenient transportation and development restrictions, the channels for collective economic development are relatively limited [114], leading to a severe imbalance in livelihood efficiency. The common issue in Shiquan and the other four counties, which are only at a basic coordination level, is the short industrial chain [115]. The insufficient development of deep and refined agricultural product processing projects makes it difficult to enhance their added value. In general, there are significant differences in the coordinated development of farmers' and county livelihood efficiency among the counties in the Qinba mountains area of southern Shaanxi. Most counties have achieved basic coordination or moderate coordination levels, but a few counties still face serious imbalance issues. Therefore, future regional development policies should formulate differentiated strategies tailored to the specific circumstances of

different counties, with a focus on counties such as Foping and Zhashui that have lower coupling coordination degrees. At the same time, it is essential to continue consolidating and enhancing the development achievements of counties that have reached moderate coordination levels in order to realize balanced development across the entire Qinba mountains area of southern Shaanxi.

3.2. Simulation Analysis of Coupled System of Farmers' Livelihood Efficiency and County Livelihood Efficiency in the Qinba Mountains Area of Southern Shaanxi

3.2.1. Scenario Design

In the coupled system of farmers' livelihood efficiency and county livelihood efficiency, the selection and debugging of core regulating variables are crucial for understanding the coupling coordination state of the two. Considering that the coupling coordination state is jointly influenced by the farmers' livelihood subsystem and the county livelihood subsystem, this study designs 17 development scenarios in 5 categories from the perspective of livelihood capital, and the basis for the setting is as follows:

(1) Human capital regulation model: According to the Law of the People's Republic of China on the Promotion of Rural Revitalization and various guidance documents issued by the National Rural Revitalization Bureau [116], education, healthcare, and population management are important components in upgrading the overall standard of living and productive capacity of poverty-eradicated areas. In recent years, under the inevitable trend of population decline, it has become particularly important to improve the quality and efficiency of human capital. Therefore, China's continued promotion of the "Healthy China 2030" strategy and the extensive development of vocational education and skills training aim to further enhance regional human capital.

(2) Physical capital regulation model: With the progress of science and technology and innovation, agricultural modernization has entered a new stage of development, in which the application of high technology, such as smart agriculture, precision agriculture technology, and biotechnology, improves the efficiency and sustainability of agricultural production, greatly enriches the material life of farmers, improves their convenience of travel, and better integrates them into the modern economic system.

(3) Natural capital regulation model: With the acceleration of urbanization and agricultural restructuring, some arable land has been abandoned due to the outflow of labor and low comparative efficiency. Against this background, the government actively promotes the adjustment of farmers' planting structures to meet market demand and improve agricultural production efficiency. The reduction in the area of arable land in the county and the exploratory attempts at farmers' planting structure together reflect the dual trends of land use change and agricultural production transformation and upgrading under the current policy environment.

(4) Social capital regulation model: With the in-depth implementation of Shaanxi Province's "14th Five-Year Plan" for the development of the information and communication industry [117], the county's communication infrastructure has been significantly improved, which not only strengthens the connection between the Qinba mountains area in southern Shaanxi Province and the outside world but also significantly increases the diversity of farmers' access to information tools and information channels. At the same time, the "14th Five-Year" public service plan emphasizes the improvement in social security [118]; through the establishment of additional work agencies, it can further improve the county's public services and improve the residents' sense of well-being and satisfaction.

(5) Financial capital regulation model: In order to improve the level of county public services, the government usually strengthens the local financial base through financial payment transfers and special fund support, which is conducive to enhancing county financial capital. Meanwhile, the Implementing Opinions on Financial Support for Comprehensively Promoting Rural Revitalization in Shaanxi Province and Accelerating the Construction of a Strong Agricultural Province [119] emphasizes that financial

resources will prioritize supporting the development of advantaged industries and will also further improve consumer financial services in counties. This means that farmers can not only obtain productive loans but also improve their quality of life through consumer finance, thus further increasing the borrowing channels and uses available to farmers.

Based on the above considerations, the specific parameter adjustments under various scenario settings are shown in Table 6.

Table 6. Parameter settings under different scenarios.

Serial Number	Mode	Scenario	Parameter Settings
0	Basic mode	Basic scenario	All parameters remain unchanged
1	Human capital regulation mode	County healthcare improvement	Basic healthcare improvement by 10%
2		County population reduction	Permanent population reduction by 10%
3		Farmers' education improvement	Farmers' education level improvement by 10%
4	Physical capital regulation mode	County agricultural technology improvement	Agricultural technology support improvement by 10%
5		County fixed assets increase	County fixed assets increase by 10%
6		Farmers' transportation tools increase	Farmers' transportation tools increase by 10%
7		Farmers' living materials increase	Farmers' living materials increase by 10%
8	Natural capital regulation mode	County arable land reduction	County arable land reduction by 10%
9		Farmers grow only cash crops	Area of cash crops equals arable land area and area of food crops is zero
10		Farmers grow only food crops	Area of food crops equals arable land area and area of cash crops is zero
11	Social capital regulation mode	County external communication increase	Number of fixed telephones per 10,000 people in the county increases by 10%
12		County social security increase	County basic social security increases by 10%
13		Farmers' information tools increase	Farmers' information tools increase by 10%
14		Farmers' information channels increase	Farmers' information channels increase by 10%
15	Financial capital regulation mode	County financial increase	County financial base increase by 10%
16		Farmers' borrowing channels increase	Farmers' borrowing channels increase by 10%
17		Farmers' borrowing uses increase	Farmers' borrowing uses increase by 10%

3.2.2. Scenario Simulation

Using Vensim PLE 7.3.5, simulations were conducted for the basic scenario and 17 scenarios within 5 types of livelihood capital regulation models. The changes in the coupling coordination degree between farmers' livelihood efficiency and county livelihood efficiency under different scenarios are shown in Table 7.

Table 7. Simulation results of the coupling coordination degree between farmers' and county livelihood efficiency under different scenarios.

Scenario	Farmers' Livelihood Capital	Farmers' Livelihood Output	Farmers' Livelihood Efficiency	County Livelihood Capital	County Livelihood Output	County Livelihood Efficiency	Coupling Degree	Development Degree	Coupling Coordination Degree	Ordering
0	0.238	0.173	0.363	0.914	0.855	0.560	0.977	0.462	0.671	11
1	0.261	0.173	0.332	0.916	0.855	0.559	0.967	0.446	0.656	14
2	0.386	0.234	0.303	0.539	0.100	0.111	0.886	0.207	0.428	18
3	0.432	0.173	0.200	0.978	1.000	0.662	0.844	0.431	0.603	17
4	0.397	0.260	0.328	0.914	0.858	0.562	0.965	0.445	0.655	15
5	0.420	0.513	0.612	1.000	0.873	0.506	0.995	0.559	0.746	7
6	0.325	0.221	0.340	0.914	0.857	0.561	0.969	0.451	0.661	13
7	0.395	0.259	0.328	0.914	0.858	0.562	0.965	0.445	0.655	16
8	0.105	0.119	0.564	0.514	0.858	1.000	0.960	0.782	0.867	2
9	0.236	0.164	0.348	0.851	0.853	0.600	0.964	0.474	0.676	10
10	0.240	0.182	0.378	0.977	0.858	0.526	0.987	0.452	0.668	12

Table 7. *Cont.*

Scenario	Farmers' Livelihood Capital	Farmers' Livelihood Output	Farmers' Livelihood Efficiency	County Livelihood Capital	County Livelihood Output	County Livelihood Efficiency	Coupling Degree	Development Degree	Coupling Coordination Degree	Ordering
11	0.307	0.302	0.492	0.930	0.906	0.583	0.996	0.538	0.732	9
12	0.333	0.350	0.527	0.918	0.865	0.564	0.999	0.546	0.738	8
13	0.387	0.452	0.584	0.917	0.870	0.568	1.000	0.576	0.759	6
14	0.462	0.592	0.642	0.919	0.877	0.571	0.998	0.607	0.778	5
15	0.252	0.432	0.857	0.915	0.855	0.560	0.978	0.709	0.832	3
16	0.323	0.514	0.795	0.918	0.876	0.571	0.986	0.683	0.821	4
17	0.389	0.778	1.000	0.921	0.892	0.579	0.964	0.790	0.872	1

The base scenario: After constructing the coupled system of farmers' livelihood efficiency and county livelihood efficiency in the Qinba mountains area of southern Shaanxi Province based on research and yearbook data, the results were obtained by keeping all the parameters unchanged and running the model directly. These results represent the base scenario. As shown in Table 7, in the base scenario, the livelihood efficiency of farmers is 0.363, while the livelihood efficiency of counties is 0.560. The coupling degree of coordination between the two is 0.671, indicating that there are still some uncoordinated problems in the livelihood efficiency of farmers and counties, which need further optimization and adjustment. Specifically, the low livelihood efficiency of farmers may be related to factors such as outdated technology, insufficient educational resources, barriers to market access, and a shortage of capital [13,120]. In contrast, county livelihood efficiency is slightly higher, but it is still affected by several development problems, such as the concentration of resources in a few areas, a single industrial structure, poor transportation and communication infrastructure, and a significant brain drain due to the siphoning effect of surrounding big cities [121]. There is a significant gap between the livelihood efficiency of farmers and counties, probably due to significant differences between counties and farmers in terms of development stage, resource acquisition capacity, economies of scale, information acquisition, and risk tolerance. The overall development level of counties is higher, while farmers are relatively disadvantaged in these aspects, leading to an imbalance in livelihood efficiency.

To intuitively identify scenarios and regulatory models that effectively promote the coordinated development of farmers' and county livelihoods, we ranked 17 regulatory scenarios and one baseline scenario based on their coupling coordination degrees. The ranking method is as follows: The scenario with the highest coupling coordination degree is ranked 1, indicating that it is the best option. Conversely, the scenario with the lowest degree is ranked 18, indicating that it is the worst option, and so on. The baseline scenario is ranked 11, indicating that 10 regulatory scenarios have a higher coupling coordination degree than the baseline, effectively promoting the coordinated development of farmers' and county livelihood efficiency. The remaining 6 scenarios may enhance livelihood efficiency on a certain scale but have not yet promoted cross-scale coordinated development. Observing the ranking of options in the last column of Table 7, it is evident that scenarios under financial and social capital regulatory models generally perform better, all enhancing the coupling coordination degree. Among them, the optimal regulatory scenario is "Farmers' borrowing uses increase" (Scenario 17). Next, we will analyze each regulatory scenario individually.

(1) Under the human capital regulation model: The coupling coordination degree tends to decrease when county medical security, the education level of farmers increases, or the county population decreases. The reason for this is mainly that the increase in these factors leads to a decrease in the livelihood efficiency of farmers. Specifically, a decrease in county population leads to more land being abandoned for farming, while improvements in education and healthcare enhance the off-farm employability of farmers, which can lead to a decrease in the number of people engaged in agricultural production. According to the theory of human capital mobility and rural hollowing out [122,123], the enhancement of human capital changes the structure of the workforce and the allocation of resources in rural areas. This can lead to issues such as the

loss of agricultural labor and decreased land use efficiency in the short term. However, in the long term, advancements in education and healthcare help improve the overall quality and health of farmers [75,76], encouraging them to adopt more efficient production methods and ultimately promoting sustainable livelihood development. Therefore, the decline in coupling coordination due to improvements in education and healthcare is a normal transitional phase, reflecting structural contradictions in the process of rural development.

(2) Under the material capital regulation model: When agricultural technology, farmers' transportation tools, or living materials improve, the coupling coordination degree tends to decrease. This is because these factors lead to a decrease in farmers' livelihood efficiency, while county livelihood efficiency increases. Specifically, advancements in agricultural technology may cause small-scale farmers to struggle to keep up with technological changes in the short term [124], leading to a relative decline in their productivity. Improvements in transportation and living materials enhance farmers' opportunities for non-agricultural employment [125], causing some labor to shift from agriculture to other industries, which can trigger structural imbalances in agricultural production, thus reducing farmers' livelihood efficiency. However, when county fixed assets increase, the coupling coordination degree rises. This is because the increase in fixed assets can improve rural public facilities and enhance agricultural productivity [126], thereby reducing the demand for labor and mitigating the negative impacts of labor transfer.

(3) Under the natural capital regulation model: A reduction in the area of arable land in the county and farmers growing only cash crops both lead to an increase in the degree of coupling coordination and the efficiency of livelihoods in the county. The main reason is that the conversion of arable land to non-agricultural use tends to yield higher economic value, while cash crops usually have higher market returns [127]. This shift may promote optimal resource allocation, enhance county livelihood efficiency, and foster coordinated development between farmers and the county. Meanwhile, planting cash crops often results in longer industrial chains [128], benefiting farmers by promoting integrated industrial development, offering additional market opportunities, and providing technical support. When farmers focus solely on food crops, the coupling coordination degree decreases. This is mainly because the per capita cash income from staple crops is relatively low, and intense market competition can harm farmers' earnings, thereby reducing their livelihood efficiency and posing challenges to food security [127,129].

(4) Under the social capital regulation model: Enhancements in external communication within the county, the expansion of information tools and channels for farmers, and improved social security can increase the coupling coordination degree by an average of 0.08. This is primarily because strengthening social capital enhances the flow of information, resource sharing, and social interactions between farmers and the county [30,105]. It enables farmers to access market information and technical support more quickly while boosting their social security and sense of safety, thus enhancing the stability and efficiency of productive lives. According to social capital theory [130], the enhancement of social capital can reduce the information asymmetry, improve the collective action and risk resistance of farmers, and also help them achieve their development goals. Indeed, enhanced social capital fosters a more favorable development environment for farmers and the county, allowing them to better utilize existing resources and tackle challenges, thereby achieving a higher level of coupling coordination development.

(5) Under the financial capital regulation model: Increases in county fiscal resources, as well as expanded lending channels and greater flexibility in loan usage for farmers, can enhance the coupling coordination degree, with an average increase of 0.17. This is primarily because financial capital exhibits liquidity and interactivity within rural economic systems [131]. Any increase in financial capital simultaneously promotes

the coordinated improvement in livelihood efficiency for both farmers and the county. When county fiscal resources increase, they can not only improve infrastructure and public services but also directly or indirectly support farmers' development through various policies and programs [132]. Similarly, when farmers have access to more lending channels and greater flexibility in loan usage, they can invest more effectively in production and improve their living conditions [133,134]. This not only enhances their livelihood efficiency but also contributes to the county's economy through increased consumption, taxation, and other means. Furthermore, increased financial capital strengthens the region's ability to mitigate risks and optimize resource allocation, further promoting the coordinated improvement in livelihood efficiency for both farmers and the county.

4. Discussion

Based on extensive data collection and a reasonable assessment of livelihood efficiency at both farmer and county levels, a coupled system of farmers' and county livelihood efficiency was constructed using a system dynamics approach. Through scenario simulations, the coordinated development changes under the change of different elements are explored, and the different impacts of each livelihood capital regulation mode on the coupled state are revealed. Compared with previous studies, this research follows the framework of sustainable livelihood theory for indicator design and relationship construction [54,135]. It also continues the measurement methods of livelihood efficiency from existing studies [4,10,107], ensuring the reliability of both the theoretical foundation and research methods. However, this study further extends the perspective of existing literature, particularly by exploring cross-scale coupling relationships. It also utilizes system dynamics simulations and regulation scenario settings to reveal the complex dynamic mechanisms of the livelihood efficiency system.

4.1. Innovative Perspective on Constructing and Analyzing a Multi-Scale Livelihood Efficiency Coupling System

Most studies focus solely on single-scale livelihood efficiency [2,4], or the relationship between livelihood efficiency and other socioeconomic systems [10]. In contrast, this paper views farmers' and county livelihood efficiency as a unified coupled system. Considering the extensive flow of resources and information between macro and micro systems [136,137], as well as the interdependent relationship between farmers' and county livelihoods in overall development [1,46], we use a cross-scale research approach. This approach explores the coupling and coordination of livelihood efficiency across different scales, revealing how farmers' livelihood efficiency is influenced by the county development environment. It also provides an in-depth analysis of how county policy implementation and resource allocation enhance farmers' livelihood efficiency. By constructing this cross-scale coupling system, we systematically uncover the transmission mechanisms of macro-level county policies and resource allocation at the micro level. We also examine the regulatory feedback of farmers' livelihood behavior on macrocounty development. This lays a theoretical foundation for understanding the multi-scale coordinated improvement in livelihood efficiency in impoverished mountainous areas.

Considering the nonlinear characteristics of efficiency improvement and the complexity and openness of livelihood systems [138,139], this paper further introduces a system dynamics approach. Using system simulation, this approach predicts the impact of different scenarios on the coordinated development of farmers' and county livelihood efficiency. It overcomes the limitations of traditional static econometric models by capturing dynamic shifts in complex relationships [140]. The simulation results show that changes in the parameters of any part of the coupled systems may affect the coupling coordination relationship between farmers' and the county's livelihood efficiency. This supports the idea from existing studies that changes in income or capital impact livelihood security [141]. It further confirms the importance of cross-scale coupling and simulation analysis in promot-

ing regional economic development, providing a solid theoretical foundation and practical guidance for sustainable development and rural revitalization in the Qinba mountains area of southern Shaanxi. Overall, considering the coupling relationships between different scales in a livelihood system is key to understanding the system's overall performance. This provides not only empirical evidence-based decision support for policymakers but also new perspectives for future research.

4.2. Rational Approach to Scenario Setting for Multi-Scale Livelihood Efficiency Coupling Coordination Analysis

In system dynamics modeling, scenario design provides an effective analytical tool for understanding system dynamics. Based on the theory of sustainable livelihoods, this paper explores the different impacts of 17 specific scenario settings within five major types of livelihood capital on the coupling coordination of livelihood efficiency between farmers and the county. This approach not only enriches the research perspective of livelihood efficiency but also provides an empirical basis for policy formulation. The sustainable livelihoods framework emphasizes that livelihoods must develop in a coordinated manner, leveraging multiple capitals. The interaction and balance of the elements within the system are crucial for livelihood sustainability [54,142]. This study found that the enhancement of a single capital may not necessarily lead to the expected coordination between farmers and counties. It may even have negative effects, further validating this perspective. In addition, it is important to recognize that various types of livelihood capitals are interconnected. They form a complex system with interactions among other elements [143]. In order to effectively improve the coupling and coordination between farmers and county livelihood efficiency, it is necessary to pay attention to the impact of policy interventions on the interactions within the system [144].

Overall, the scenario setting of this paper has shown the impact of the individual regulation of various livelihood capitals on the degree of coordination of the coupling of farmers' livelihood efficiency and county livelihood efficiency as much as possible. However, in the development of rural revitalization, it is often necessary to integrate multiple livelihood capitals to exert greater synergy [145]. Due to the synergistic and substitution effects among livelihood capitals [146], in resource-limited post-poverty mountainous areas such as the Qinba mountains in southern Shaanxi, it is crucial to optimize the capital structure [147]. This enhancement can promote the coordinated improvement in both farmers' livelihood efficiency and county livelihood efficiency. Therefore, designing a joint regulation strategy by combining two or even multiple livelihood capitals may be a more reasonable approach for scenario setting. Taking the joint regulation of human capital and physical capital as an example, relying solely on education to improve farmers' non-farm employment ability can lead to a structural shortage of human capital. This change in farmers' occupations and outflow may negatively impact agricultural and rural development [148,149]. If the county infrastructure is improved through fixed asset investment, it can promote social development by enhancing agricultural productivity [150]. Ultimately, this creates a joint regulation effect that favors the coordinated improvement in both farmers' and county livelihood efficiency. By leveraging the synergistic effect of different livelihood capitals, strategy combinations can be developed for resource-constrained areas such as post-poverty mountainous regions. This approach helps address complex challenges and strengthens the foundation for the sustainable development of the county economy.

4.3. Recommendations

In order to promote more efficient livelihoods, a combination of macro- and microscales is necessary. At the macroscale, infrastructure, resource utilization, and policy effects should be used to promote high-quality development in counties. Specifically, first, investment in infrastructure such as rural roads, logistics networks, and distribution centers for agricultural products should be increased. This will effectively reduce transportation costs, minimize losses of agricultural products, and improve logistics efficiency [99,151].

Second, the government should promote the effective construction of interest linkage mechanisms such as agricultural cooperatives. Under the smallholder economic model, the livelihood conditions in mountainous areas that have escaped poverty are relatively limited, making it more difficult to form economies of scale. Therefore, promoting the consolidation of agricultural production entities through macro policies is necessary to optimize the allocation of public resources in the county and accelerate the dissemination of advanced technology [152]. Additionally, the distribution and configuration of primary medical institutions should be adjusted in a timely manner to minimize the redundancy of medical resources caused by the hollow village phenomenon. Finally, the government should provide appropriate technical support, meteorological services, and policy guidance, coordinate annual planting plans, and ensure that the introduction of cash crops aligns with the overall industrial layout [153].

At the microscale, farmers should be mobilized to produce sustainably through education and training, talent measures, and diversified planting. Specifically, first, skill training and continuing education are recommended for farmers to help them master modern agricultural technology and management knowledge [154]. Second, well-educated farmers should be encouraged to participate in modern agricultural production. It is suggested that the return of talents be promoted through the development of digital agriculture and the provision of talent subsidies. Additionally, it is recommended that farmers adopt diversified crop cultivation strategies. According to livelihood conditions and market demand, high-value-added cash crops such as fruits, medicinal herbs, and tea should be reasonably planted to improve productivity and economic benefits [155]. Finally, farmers should be encouraged to maintain a certain percentage of food cultivation. It is recommended that farmers' income from planting food crops through financial subsidies and other means and that the production mechanism of rotating various staple foods such as corn and wheat be promoted to guarantee farmers' livelihood needs and food security [156,157].

In order to promote the coupling and harmonization of county and farmers' livelihood efficiency, it is recommended to strengthen social and financial support. At the county level, first, it is recommended to upgrade information and communication infrastructure to strengthen external links and promote urban–rural coordination [158]. Second, social basic security should be improved, and community services optimized to expand social security coverage and enhance livelihood stability in the county. Finally, it is recommended to enhance county financial input and set up special funds for agricultural and rural development, which is conducive to achieving common prosperity and coordinated social development [159]. At the farmers' level, first, it is recommended to promote smartphones and related applications, enabling farmers to obtain market information in a timely manner and better adapt to changes in the external environment. Second, it is recommended to reduce the cost and threshold of borrowing and establish more mobile financial service points in remote areas, enabling more farmers to successfully obtain financial support [133]. Additionally, financial support policies should continue to be strengthened to expand the availability of credit for farmers. Finally, the diversification of farmers' borrowing purposes should be gradually promoted, encouraging them to develop agricultural product processing, rural tourism, and other related sideline industries.

In addition to coordinating resources to support agricultural and rural development, as well as the livelihoods of farmers, local governments should consider the actual development of their areas. They should also account for the industrial resources of neighboring regions to improve livelihood conditions based on local circumstances. According to the results of this paper, the majority of the counties with relatively low coupling and coordination between farmers and county livelihood efficiency are located in the northern and southern fringes of the Qinba mountains area in southern Shaanxi. It is recommended that these counties actively promote cross-regional resource sharing and industrial cooperation, which will be conducive to addressing industrial shortcomings and realizing livelihood development. For example, Foping is adjacent to Xi'an, and it is recommended that it enter into a targeted supply agreement for agricultural products with Xi'an, which will largely

alleviate the high transportation costs caused by unfavorable geographic conditions [160]. At the same time, due to the strict ecological protection and relatively limited resource development in such counties, it is recommended that they prioritize the development of the digital economy and online service industries in order to reduce their dependence on transportation. Lan'gao, Pingli, and Baihe are adjacent to Chongqing Municipality and Shiyan Municipality, respectively. Although these three counties belong to the core ecological tea production area in southern Shaanxi, they have a low degree of industrialization, resulting in a low proportion of tea deep processing and finishing. It is recommended that these three counties reach cooperation with Chongqing and Shiyan to transport tea across the province to neighboring urban factories for deep processing. This will not only maximize the saving of transportation costs but also help to enhance their cross-scale livelihood coordination from the perspective of industry chain extension [114].

In post-poverty mountainous areas like Hanzhong, which has a better geographical location and comprehensive development, the construction of special infrastructure should be continuously promoted. This includes logistics and distribution centers for traditional Chinese medicinal herbs. These measures aim to ensure that high-quality agricultural products can be efficiently circulated in the market and that the location advantage can be transformed into a livelihood advantage [113]. This will also help Hanzhong accelerate its integration into national strategies such as the Yangtze River Economic Belt and further promote the coordinated improvement in the efficiency of its farmers and county livelihoods. Overall, the above recommendations are not only applicable to the Qinba mountains area in southern Shaanxi but also provide an important reference for other similar regions. By generally strengthening effective and broad-based policies, such as social and financial support, post-poverty mountainous areas will enhance their overall development. Additionally, formulating industrial development policies and regional cooperation mechanisms according to local conditions will further promote this progress. These efforts will effectively improve livelihood efficiency at multiple scales, realizing high-quality economic development and sustainable livelihood improvement.

4.4. Research Limitations and Future Improvement Directions

Although this paper meticulously explores the coordinated development of farmers' and county livelihood efficiency across various scenarios and expands the application field of the system dynamics approach, it still has several shortcomings. On the one hand, although this paper and previous studies have used the DEA model to measure livelihood efficiency [4,10,107], which examines the rationality of resource utilization as comprehensively as possible, there may be some limitations to the model. The DEA model assumes that all decision-making units operate under the same conditions. However, in practical applications, counties and farmers may encounter varying technical efficiencies and external constraints due to differences in resources, environments, and policies [161]. Additionally, the DEA model is quite sensitive to extreme values. Individual samples that are excessively high or low can disproportionately affect the assessment of livelihood efficiency. This can lead to a decrease in the precision of livelihood efficiency measurement [162]. On the other hand, this paper focuses on the static regulatory effects of livelihood capital in the current context but lacks dynamic considerations in the time dimension. Livelihood capital can exhibit different trends and interactions at various stages of development and economic cycles. Strict control measures in Shaanxi Province from 2021 to 2022, due to the COVID-19 pandemic, prevented long-term studies on farmers' livelihood behaviors, resulting in insufficient reflection of these dynamic factors in the scenario analysis.

The direction of future improvement lies in the following data. First, future research should consider combining other efficiency measurement methods to supplement the DEA model. For example, methods such as stochastic frontier modeling or weighted fuzzy comprehensive evaluation can better address data heterogeneity and uncertainty [163,164]. If the livelihood process includes undesirable outputs such as pollutants, the SBM or EBM model can be switched to provide a more comprehensive understanding and measurement

of livelihood efficiency [165]. Second, the weights of various livelihood capitals and livelihood outputs can be improved by combining objective and subjective methods. Methods such as the Delphi method, hierarchical analysis, and entropy value give comprehensive weights to each indicator. Then, calculate livelihood efficiency using the DEA method. This addresses the issue where entropy weights may not fully reflect the real importance of the indicators due to the abnormal fluctuation of individual data and the normalization of the specific series to be smooth [166]. Additionally, long-term tracking research should be persistently carried out, and a sound data collection and monitoring mechanism should be established to dynamically track changes in the livelihood efficiency of farmers and counties. Regularly collecting relevant data on farm household income, production costs, borrowing and lending utilization, market price fluctuations, etc., the impact of policy interventions and market changes on livelihood efficiency can be more accurately assessed. This will not only assist in adjusting and optimizing policy measures but also aid farmers in making more rational livelihood decisions. Finally, it is important to strengthen the consideration of regional differences by analyzing variations in livelihood efficiency among farmers and counties. Understanding these differences and their impact on coordinated development will offer more scientific and practical guidance for improving the livelihood efficiency of both farmers and counties.

5. Conclusions

The coupled system of farmers' livelihood efficiency and county livelihood efficiency is a complex open system comprising multiple elements such as human capital, physical capital, and natural capital. The interactions and feedback mechanisms among these elements contribute to the ongoing development and evolution of the system. Based on the research results of farmers in the Qinba mountains area and the statistical data of each district and county, this study measures the coupling coordination degree between farmers' and county livelihood efficiency. A system dynamics model of cross-scale coupling is constructed based on this, and 17 scenarios based on 5 regulation modes are designed and simulated to examine the effects of various changes on the coupling coordination degree. The research conclusions are as follows:

(1) The coupling coordination degree between farmers' livelihood efficiency and county livelihood efficiency in the Qinba mountains area of southern Shaanxi is 0.623. This indicates a medium coordination level overall, which still requires further optimization and adjustment. Among these cities, Hanzhong shows a higher coupling coordination degree than Ankang and Shangluo. Foping is in a state of serious imbalance. Five districts and counties, including Shiquan, Zhashui, Baihe, Pingli, and Lan'gao, exhibit basic coordination. Meanwhile, 19 districts and counties, such as Lueyang, Ningqiang, and Yang, demonstrate moderate coordination.

(2) Among the 17 scenarios for livelihood capital regulation, increasing county fixed assets, growing only cash crops, increasing major social capital or financial capital, and decreasing county arable land are all conducive to a higher coupling coordination degree. When human capital changes, improvements in education and healthcare, along with population reductions, will decrease the coupling coordination degree. This indicates that the negative impacts of changes in production structure and resource allocation must be avoided while enhancing farmers' livelihood capacity. When physical capital changes, increasing fixed asset investment can enhance the degree of coordination. However, increasing agricultural technology or living materials may result in a short-term decrease in coupling coordination. When natural capital changes, reducing the area of arable land or planting only cash crops can enhance the degree of coupling coordination. In contrast, a singular model of food cultivation may have negative effects. Changes in social capital can increase the average coupling coordination degree by 0.08, as the flow of information, resource sharing, and social interactions between farmers and counties are often improved. This improvement is beneficial for improving the efficiency, quality, and stability of production and

life. Under the financial capital regulation model, the average coupling coordination degree can increase by 0.17. An increase in county fiscal investment, along with improved loan channels and uses for farmers, leads to a coordinated improvement in the livelihood efficiency of both farmers and the county.

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