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RESEARCH ARTICLE

Synchronous Development Strategy of China's New Four Modernizations: An Analysis Based on Interactive Mode

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ABSTRACT The Chinese government has proposed a synchronous development strategy for new urbanization, industrialization, informatization, and agricultural modernization (called ''New Four Modernization,'' NFM), which provides new ideas for solving social sustainable development problems such as large urban-rural gaps, irrational industrial structures, and environmental pollution. This study aims to examine their interactive modes and provide a theoretical basis and empirical evidence for the synchronous development of NFM. The analysis started with the interaction mechanisms of new urbanization, industrialization, informatization, and agricultural modernization. Principal component analysis (PCA) was used to comprehensively evaluate the level of NFM development. A vector auto-regression (VAR) model was constructed to analyze the interaction effect empirically. The findings were as follows: (1) China's new urbanization, industrialization, informatization, and agricultural modernization development levels were rising, and there was a long-term equilibrium relationship between them. (2) The Granger joint test found that the combined effects of any three developments in new urbanization, industrialization, informatization and agricultural modernization have a significant causal relationship with the development of the other, which showed that the synchronous development of NFM had an inherent motivation. (3) New urbanization occurred at the core of NFM interaction mode and was the main driving force for the development of the other three modernizations. Lastly, this study provides a new case for better understanding the interaction mode of NFM in emerging countries such as China, and provides Chinese experience for developing countries.

INDEX TERMS New four modernization, sustainable social development, interactive mode, principal component analysis (PCA), vector auto-regression model (VAR).

I. INTRODUCTION

In the early stages of reform and opening up, due to limited resources such as human capital, material resources, scientific and technological capabilities, and financial resources, China adopted a strategy of unbalanced development [1]. This unbalanced development strategy has had a positive impact on China's social and economic development [2]. After decades of development, China has established the world's most complete modern industrial system [3], becoming the world's largest manufacturing country and second largest economy. Urbanization construction in China has experienced a process of low starting point, strong momentum and rapid speed along with the advancement of modern industrialization [4]. The permanent urban population has increased from 170 million in 1978 to 902 million in 2020,

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and the corresponding urbanization rate has increased from 17.92% to 63.89%. China's informatization development is also very rapid, with the internet penetration rate and mobile phone penetration rate reaching 93.5% and 112.91% respectively (Sourced from the National Bureau of Statistics of China). Due to the continuous progress of agricultural technology, China's agricultural modernization has made great progress. The output of China's major agricultural products, such as grain, cotton, rapeseed, meat, fruits and vegetables, has already ranked first in the world. Since reform and opening up, China has lifted 770 million poor rural people out of poverty, accounting for more than 70% of the global poverty reduction population during the same period. However, with the continuous advancement of China's modernization process, problems such as unbalanced regional development, unsustainable economic growth, and large urban-rural gaps have gradually emerged because of this strategy. In this context, the Chinese government proposes to promote the synchronous development of new urbanization, industrialization, informatization and agricultural modernization [4], which is also called the ''New Four Modernization (NFM)'' synchronous development strategy.

Chinese modernization was first proposed at the 20th CPC National Congress in October 2022. One of the important goals is to realize new urbanization, industrialization, informatization and agricultural modernization by 2035 [6]. Therefore, NFM is an important part of China's modernization path. Promoting the synchronous development of NFM is the basic path to realizing China's modernization, and is also an important strategic deployment to start a new journey of comprehensive construction of China's modernization path. In recent years, with the development of urbanization and industrialization, a large number of surplus laborers in China have entered cities and non-agricultural industries for employment, which not only promotes the development of industrialization and agricultural modernization, but also brings about the expansion of urban scale [7], [8]. At present, information technologies such as big data, artificial intelligence, and cloud computing are developing rapidly. China's e-commerce transaction volume has surged from 33 billion yuan in 1999 to 37.21 trillion yuan in 2020, an increase of more than 1,000 times over the past 20 years. Informatization has been integrated into various industries of the national economy, further promoting industrial development and social progress [9], [10]. New urbanization, industrialization, informatization and agricultural modernization, which are interconnected [11], have become an important driving force for the sustainable development of China's social economy.

The proposed NFM synchronous development strategy is crucial to solving China's current social contradictions, such as irrational industrial structures, large urban-rural gaps, and environmental pollution [12]. It also provides developing countries with new ideas and practical experience to solve similar problems. However, the following questions may arise. Is there any theoretical basis or empirical evidence to support the synchronous development strategy of NFM? Does the synchronous development of NFM have an intrinsic motivation? What are the positions and roles of new urbanization, industrialization, informatization, and agricultural modernization in NFM? As the world's largest developing country, theoretical and empirical research on the interactive mode between China's new urbanization, industrialization, informatization, and agricultural modernization is significant in answering the above questions.

Although scholars have conducted a lot of research on urbanization, industrialization, informatization, and agricultural modernization, they mainly focus on the aspects of development pattern, driving force, and level. Zhang et al. analyzed the development pattern and driving factors of county urbanization and found that the level of urbanization in southeast coastal counties is relatively high, but the development speed is slower than that in central and western regions. Poor resource endowment is the main factor hindering the development of urbanization at the county-level [13]. Gu believes that industrialization, modernization, globalization, marketization, and administrative power are the five driving forces of the urbanization process [14]. Huang et al. used AHP and entropy methods to measure Kunming's urbanization level from 2015 to 2019, and the results showed that Kunming's urbanization level continued to improve [15]. Merzlikina et al. elaborated on the main characteristics of new industrialization and revealed the mechanism of regional economic interests converging under new industrialization [16]. Tao et al. believe that China's industrialization process has gone through five stages: accumulation period, exploration period, accelerated development period, high-speed development period, and shifting period [17]. Ragulina et al. used comparative analysis to compare the level of social informatization between Russia and OECD countries, and found that the development level and speed of social informatization in modern Russia is relatively low [18]. Wang et al. used entropy method to measure the level of agricultural modernization in Shaanxi Province, and the results showed that the overall trend of agricultural modernization in Shaanxi Province was on the rise, but the rate of increase was not fast [19].

Second, the relationship between them is studied in terms of agricultural informatization, urbanization and industrialization, industrialization and information integration, and agricultural industrialization, etc. Through the integration of informatization and agriculture, transaction costs can be reduced, agricultural management can be improved, and a range of modern agricultural industrialization models can be developed [20]. Additionally, new industrialization and new urbanization were found to have a mutually beneficial impact on each other, with a long-term cointegration relationship [21]. Wang et al. demonstrated that urbanization levels played a significant role in reducing the urban-rural income gap [22], [23]. Liu et al. used the threshold regression model of static panel data to explore differences

in the interaction effects between informatization and new urbanization processes in different regions of China [24]. Wang and Zhou's study of the interaction between urbanization and agricultural modernization in Shandong Province shows that agricultural modernization is the Granger cause of urbanization, while urbanization is not the Granger cause of agricultural modernization. Agricultural modernization has a positive long-term effect on urbanization, while urbanization has a short-term negative effect on agricultural modernization [25]. Wei pointed out that under the new normal of China's economic transformation and upgrading, promoting the coordinated development and positive interaction of Gansu's new urbanization and agricultural modernization will inevitably become an important task of economic and social development in the new era [26].

Finally, studying urbanization, industrialization, informatization, and agricultural modernization from the perspective of sustainable development, environmental protection, carbon emissions, and renewable energy has become a popular research field in recent years [27], [28], [29], [30], [31], [32], [33]. However, in the existing literature, few reports analyze the interactive mode of NFM, making it difficult to answer the above questions and understand China's synchronous development strategy for NFM. Therefore, this study may help to fill gaps in the existing literature and have the following potential contributions: (1) We provided a framework for analyzing the interactive model of new urbanization, industrialization, informatization, and agricultural modernization. Specifically, we reported that the combined effects of any three developments in new urbanization, industrialization, informatization and agricultural modernization had a significant causal relationship with the development of the other based on the Granger causality test, which showed that the synchronous development of the NFM had an inherent motivation. (2) This paper provided a new case for better understanding the interaction mode of NFM in emerging countries such as China, and provided Chinese experience for developing countries.

This study first analyzed the interactive mechanism of the NFM. Then, we constructed an evaluation index system for the development of the NFM, and used the PCA method to measure the development index of China's new urbanization, industrialization, informatization and agricultural modernization from 1999 to 2019. Finally, the VAR model was used to analyze the interactive mode of China's NFM. The remainder of this paper is organized as follows. Section II makes theoretical analysis on the interaction mechanisms of new urbanization, industrialization, informatization and agricultural modernization. Section III introduces the methods and data sources used in our empirical analysis. Section IV presents the empirical results. Section V draws research conclusions and discussions, which will help us in understanding the NFM synchronous development strategy proposed by the Chinese government. Finally, we proposed policy recommendations based on the problems existing in the synchronous development of China's NFM.

II. INTERACTIVE MECHANISM ANALYSIS

The core of new urbanization is "people-oriented" [34], which pays more attention to ecological protection, improves the construction of public infrastructure and the supply of public services. With the advantages of capital, technology and talents, new urbanization can accelerate industrial agglomeration, optimize industrial structure, provide support for agricultural modernization, and ensure food production security. New urbanization is the link and carrier of the other three modernizations, which is reflected in several aspects. First, the infrastructure and public services provided by new urbanization are fundamental guarantees for industrialization [35]. The advantages of new urbanization in the accumulation of talents, capital, and technology provide human resources and technical support for industrialization. Second, the development of new urbanization accelerates the transfer of surplus rural labor to cities and towns [36], thereby expanding the consumption demand for farm products and providing a broad market for the development of agriculture. New urbanization development also provides advanced management concepts, technical and financial support for agricultural modernization, which drives the development of agricultural technology and the adjustment of agricultural industrial structure [37], [38]. It also provides protection and support for modern agriculture in terms of health culture and social systems, which helps improve farmers' quality of life and promote urban-rural integration. Third, new urbanization is the carrier of informatization. In the new urbanization process, the demand for information products encourages informatization. Simultaneously, new urbanization provides favorable conditions for the development of informatization in talent reserves, technological innovation, and capital accumulation.

The intended meaning of new industrialization is to achieve industrialization with high technological content, low environmental pollution, and low resource consumption, which is regarded as the engine for the other three modernizations. The impact of new industrialization on the other modernizations is mainly manifested as follows. First, the continuous development of new industrialization will accelerate industrial agglomeration, optimize industrial structure, and cause the proportion of secondary and tertiary industries to gradually increase, which will attract the continuous transfer of surplus rural labor to cities and towns, thus providing power for the development of urbanization. Second, informatization is produced at a particular stage of industrialization [39]. It can be argued that industrialization is a prerequisite for informatization. The information infrastructure and hardware on which informatization depends for survival require the support of industrialization. Finally, industrialization can provide new technologies for agriculture and promote agricultural mechanization, automation, and large-scale production, thereby contributing to the realization of agricultural modernization [40].

Informatization is a product of urbanization and industrialization at a particular stage. It is the process of productivity

transformation from tangible materials such as industrial products to informational products. It is based on computers, mobile Internet, big data, and other information technologies to achieve urbanization, intelligent industrialization, and agricultural modernization [41]. Informatization is an accelerator for the development of the other three modernizations, and its primary functions are as follows. Firstly, informatization is the multiplier and booster of urbanization development. The combination of informatization and urbanization can create smart cities. The use of information technology can help cities and towns optimize their industrial structure and form a technological innovation industry centered on intellectual talents, transforming the production and lifestyle of urban residents. Secondly, the integration of informatization and industrialization can create smart industries. Informatization can optimize the allocation of production factors by improving market information transparency and reducing the impact of information asymmetry, thus helping to improve industrial efficiency [42]. Thirdly, the combination of informatization and traditional agriculture, which can help in the industrial upgrading of conventional agriculture, allows farmers to communicate with the external market and strengthens agricultural production, circulation and distribution links, thus reducing the market risk of agricultural products.

Agricultural modernization requires traditional agriculture to realize agricultural industrialization, scale, and intensification using advanced agricultural production, operation and management concepts, and agricultural technology [43], [44]. Agricultural modernization provides production factors and material security for the other three modernizations, and plays a significant role. First, agricultural modernization promotes the transfer of large amounts of surplus rural labor to cities and towns to provide labor for the development of urbanization. Second, the development of agricultural modernization offers a material basis for industry, such as supplying the industrial sector with necessary raw materials and primary products [45]. Finally, agricultural modernization requires industrialization and informatization to provide agricultural equipment and information technology, which promotes industrialization and informatization.

In summary, new industrialization, informatization, urbanization, and agricultural modernization are organically interconnected, interacting, and promoting each other. Urbanization is the carrier, industrialization is the engine, informatization is the accelerator, and agricultural modernization is the basis of the other "three modernization". The synchronous development of NFM means that each system exerts its advantages under the influence of the market to achieve mutual penetration and mutual promotion, thus improving the optimal allocation of resources. Eventually, a development pattern will be formed in which cities lead rural areas, industry and farmers are mutually beneficial, urban and rural areas are integrated, and industry promotes agriculture, achieving healthy development of the national economy and society (Seeing Figure 1) [46].

TABLE 1. Indicator system for assessing the development level of industrialization, informatization, urbanization and agricultural modernization.

Subsystem	Indicators
Urbanization development level	Urbanization rate (%)
	Per capita disposable income of urban residents (RMB)
	Urban unemployment rate (%)
	Number of college students (per 100,000 people)
	Number of urban health technicians (per 1,000 people)
	Number of public transportation vehicles (total)
	Urban road area (per capita)
	Number of special equipment for city appearance (total)
	Per capita public green space area (square meters/person)
Industrialization development level	The proportion of non-agricultural industries GDP (%)
	Industrial output value (per capita)
	Number of industrial enterprises (per 10,000 people)
	Profit of large-scale industrial enterprises (Per capita)
	Industrial cost profit margin (%)
	industrial new product R & D Expenses (Per capita)
	R & D personnel full-time equivalent (total)
Informatization development level	Internet Penetration (%)
	Mobile phone penetration (%)
	Annual subscriptions (per 100 people)
	Number of domain names
	Number of the webpage
	Mobile switch capacity (ten thousand households)
	E-commerce transaction volume (trillion)
Agricultural modernization development level	Disposable income of rural residents (Per capita)
	Electricity consumption of rural residents (Per capita)
	Rural mechanical power (Per capita)
	Rural effective irrigation area (Per capita)
	Number of rural health technicians (per 1,000 people)

III. METHODS AND DATA SOURCES

We constructed a comprehensive indicator system to evaluate the development index of China's new urbanization, industrialization, informatization and agricultural modernization from 1999 to 2019 using principal component analysis. Then, the vector auto-regressive (VAR) model was used to empirically analyze its interaction effect. This paper used R (version 4.2.1) programming language to process data and models.

A. MEASURING THE DEVELOPMENT LEVEL

1) INDICATOR SELECTION AND DATA SOURCES

The construction of indicator system is a systematic project. Based on previous studies [15], [17], [19], [47], [48], [49], this paper focuses on the connotations and characteristics of new urbanization, industrialization, informatization, and agricultural modernization, establishing the comprehensive index system shown in Table 1.

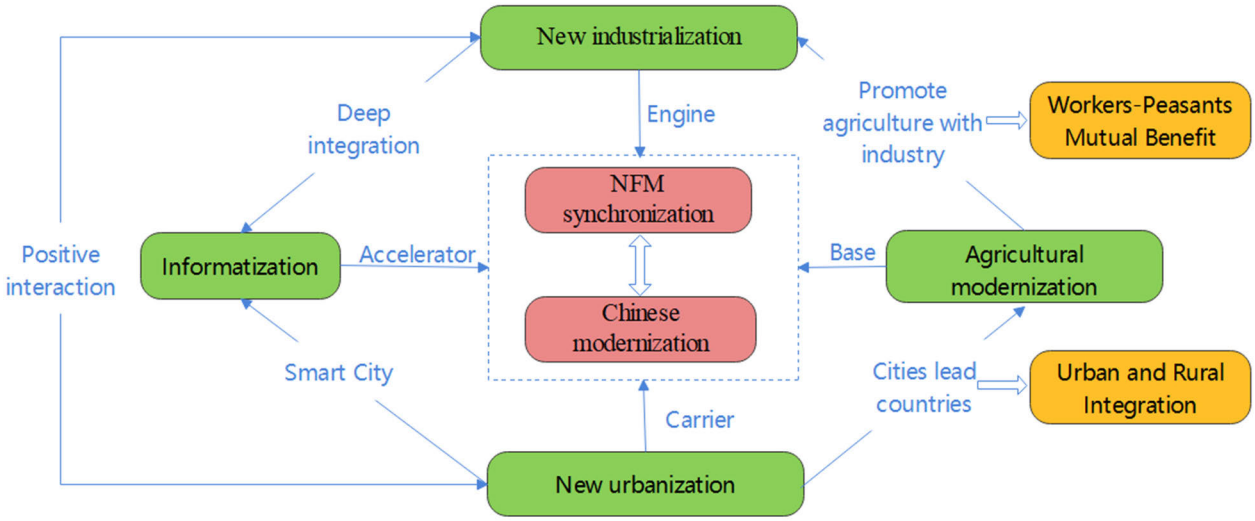

FIGURE 1. Conceptual framework of the NFM interaction mechanism.

The original data for the indicators in this study were mainly extracted from the China Statistical Yearbooks (2000-2020), the database of the China Internet Information Center (http://www.cnnic.net.cn/6/132/index.html), and the website of the Ministry of Commerce of China (http://www.mofcom.gov.cn). A few missing data in a specific indicator were obtained using data interpolation.

2) EVALUATION MODEL

Principal component analysis (PCA) was employed to solve the multivariate information overlap problem [50]. It objectively determines the weight of the comprehensive evaluation model by the common factor eigenvalue, which avoids arbitrary subjective weight assignment and is more scientific [51]. Therefore, considering that the above indicators were numerous and relevant, this study adopted the PCA for a comprehensive evaluation. The main steps were as follows:

a) The original data were standardized to eliminate errors caused by the different measurement units of the different indicators.
b) Principal components were selected according to the calculated eigenvalues and variance contribution rate, such that the cumulative variance contribution rate of the primary component factors was less than 90%.
c) The score F_i of each principal component factor was calculated.
d) The weight ω_i of each principal component factor was calculated using the following calculation formula:

$$\omega_i = \frac{\lambda_i}{\sum_{i=1}^{n} \lambda_i} \tag{1}$$

where i = 1,2,3…n, λ_i is the eigenvalue of the i-th principal component factor.

e) Finally, the final score F of the NFM subsystem was calculated. The formula is as follows:

$$F = \sum_{i=1}^{n} \omega_i F_i \tag{2}$$

where ω_i is the weight of the i-th principal component factor, and F_i is the score of the i-th principal component factor.

According to the above method, we calculated the development level of new industrialization, urbanization, agricultural modernization and informatization in China from 1999 to 2019. To facilitate subsequent analysis and research, we normalized and indexed the subsystems over the years without changing their relative development levels. The formula used is as follows:

$$F' = \frac{F_m - 2F_{min}}{F_{max} - 2F_{min}} \times 1000 < F' \leq 100 \tag{3}$$

where F_m is the subsystem score in year m of China, F_{max} is the year's value with the highest score in the subsystem, and F_{min} is the score of the year with the lowest score in the system. According to the above calculation formula, China's new urbanization development index UR, industrialization index IND, informatization index INF, and agricultural modernization index AG were obtained over the years.

B. INTERACTIVE MODEL

The vector auto-regressive (VAR) model, proposed by Nobel Prize winner Sims in 1980, is widely used to analyze the interactive relationships between multiple variables [52], [53]. It constructs a model by taking each endogenous variable as a function of the lag value of all endogenous variables in the system, thereby extending the univariate auto-regressive model to the vector auto-regressive model composed of multiple time series [54]. The general mathematical expression is

as follows:

$$Y_t = C + \eta_1 Y_{t-1} + \eta_2 Y_{t-2} + \ldots \eta_{k-1} Y_{t-k+1} + \eta_k Y_{t-k} + \varepsilon_t$$

where $\eta_1, \eta_2, \ldots, \eta_{k-1}, \eta_k$ are the coefficient matrices to be estimated, Y_t is the column vector of the m-dimensional endogenous variable, k is the lag order of the model, C is a constant term and ε_t is a random disturbance term. According to the above evaluation model, we obtained the development indexes of China's new urbanization, industrialization, informatization, and agricultural modernization, marked as UR, IND, INF, and AG, respectively. This study uses its natural logarithm to eliminate the influence of heteroscedasticity. The VAR model with lag period k is established as follows:

$$\begin{bmatrix} LNUR_t \\ LNIND_t \\ LNINF_t \\ LNAG_t \end{bmatrix} = C + \sum_{p=1}^{k} \phi \begin{bmatrix} LNUR_{t-p} \\ LNIND_{t-p} \\ LNINF_{t-p} \\ LNAG_{t-p} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \end{bmatrix} \quad (4)$$

IV. RESULTS ANALYSIS

Consistent with the research design, this section first presents the development index results for new urbanization, industrialization, informatization and agricultural modernization. We then use the results of the VAR model to analyze the interaction relationship

A. MEASUREMENT AND ANALYSIS OF THE DEVELOPMENT INDEX OF NEW URBANIZATION, INDUSTRIALIZATION, INFORMATIZATION AND AGRICULTURAL MODERNIZATION

The key to a comprehensive evaluation using principal component analysis is the choice of the principal component factors. As mentioned in the evaluation model in the previous section, the choice of the number of principal component factors should ensure that the cumulative variance contribution rate is greater than 90%. As listed in Table 2, three principal component factors were selected for UR and IND, with cumulative variance contribution rates of 98.040% and 96.295%, respectively. The number of principal component factors for INF and AG was set to 2 and 1, respectively, and their cumulative variance contribution rates reached 95.921% and 97.829%, respectively.

After determining the principal component factor, the weight was calculated based on the eigenvalue. The development indices of new urbanization, industrialization, informatization, and agricultural modernization were calculated using formulas (1)–(3). The results are shown in Figure 2.

From the perspective of development trends, new urbanization, industrialization, informatization, and agricultural modernization were generally rising. From the perspective of fluctuations, new industrialization fluctuated greatly, while the development of urbanization, informatization, and agricultural modernization was relatively stable. A possible reason for this is that industrialization is more sensitive to economic development. From the perspective of overall development level, China's new industrialization, urbanization, informatization, and agricultural modernization were quite different, showing a decreasing pattern in turn. Moreover, the development of informatization and agricultural modernization lagged behind new urbanization and industrialization, which showed that there were obvious problems of unbalanced and unsynchronized development in China's NFM subsystem.

B. EMPIRICAL ANALYSIS OF INTERACTIVE MODE

1) THE UNIT ROOT TEST

The premise of establishing a time series model was to ensure the stability of each variable to avoid the problem of pseudo regression. This study used the unit root test and Augment Dickey-Fuller (ADF) to test the time series. The results of the unit root tests are presented in Table 3. The ADF test values of the LNUR, LNIND, LNINF, and LNAG time series were all greater than the critical values of 1%, 5%, and 10%, respectively. The corresponding P-values were 0.64, 0.20, 0.95, and 0.76, respectively, indicating that the time series was not stationary. After the first-order difference of the series, the ADF test values were all less than the critical value of 5%. It shows that all the time series of this empirical test under the 5% confidence level satisfy the first-order integer series.

2) THE COINTEGRATION TEST

This study uses the Johansen Cointegration method to verify whether there is a long-term equilibrium relationship between the variables. The test results are listed in Table 4. The variables LNUR, LNIND, LNINF, and LNAG have a cointegration relationship at a significance level of 5%, and there is a long-term stable equilibrium relationship between the variables.

As the variables passed the cointegration test, it was appropriate to use OLS to estimate the cointegration equation. Finally, the following cointegration equations passed the model test at a significance level of 10%, and the test results are listed in Table 5. The cointegration equation can be written as:

$$\begin{aligned} &LNAG \\ &= \underset{(4.74)}{0.519}LNUR + \underset{(4.67)}{0.417}LNINF + \underset{(2.01)}{0.124}LNIND - \underset{(-1.85)}{0.270} \end{aligned}$$

The cointegration equation shows that new urbanization has the most significant positive effect on agricultural modernization in China. This is because the rapid development of urbanization in China has provided many jobs for farmers and a broad market for rural areas, thereby accumulating funds for agricultural mechanization and automation. Informatization is the second driving force of agricultural modernization. In the past two decades, the development of the mobile Internet has greatly improved underdeveloped rural information, and the marginal effect of information elements

TABLE 2. The cumulative variance contribution rate of principal component factors.

	UR		IND		INF		AG	
Factors	Eigenvalues	Cumulative variance contribution rate (%)	Eigenvalues	Cumulative variance contribution rate (%)	Eigenvalues	Cumulative variance contribution rate (%)	Eigenvalues	Cumulative variance contribution rate (%)
1	6.933	69.327	4.974	71.055	6.166	88.087	4.891	97.829
2	2.052	89.847	0.937	84.441	0.548	95.921	0.093	99.684
3	0.819	98.040	0.830	96.295	0.219	99.054	0.011	99.905
4	0.115	99.189	0.201	99.169	0.055	99.839	0.004	99.905

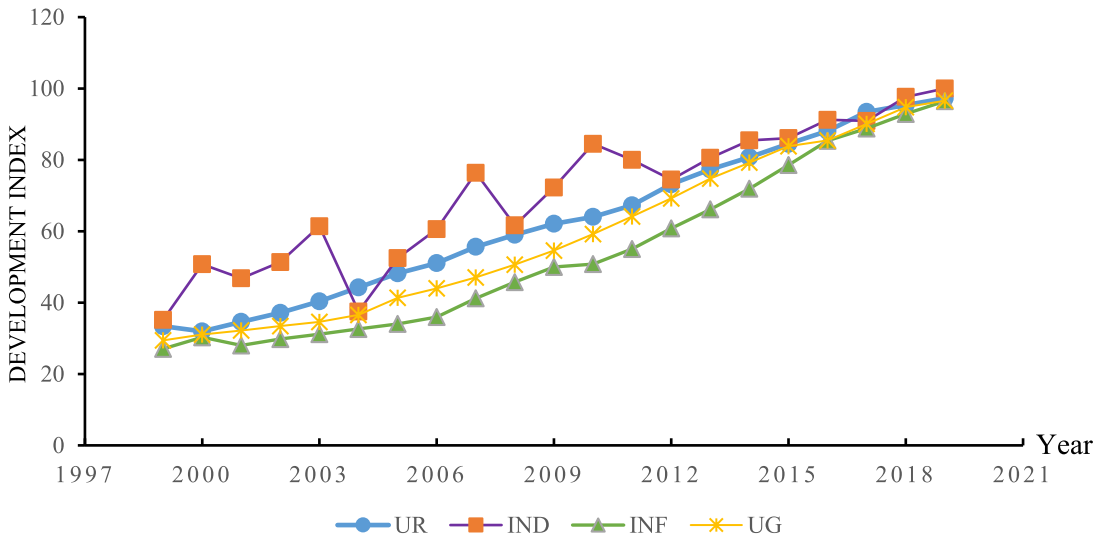

FIGURE 2. China's new urbanization, industrialization, informatization, and agricultural modernization development index.

has become more evident. Industrialization has the weakest stimulating effect on agricultural modernization. This may be because industrialization is mainly concentrated in large and medium-sized cities, and has a small radiation effect on rural areas.

3) THE ESTABLISHMENT OF THE VAR MODEL

Before establishing the VAR model, we select an appropriate lag order. This study used relevant standard criteria to determine the lag order. AIC criterion and SC criterion are usually used to determine the optimal lag order of VAR model. If the lag order corresponding to the minimum of AIC and SC is the same, then the lag order is the optimal lag order. If the order of lag corresponding to the minimum of the two criteria is different, it is necessary to determine the optimal lag according to LR statistics. In this paper, as shown in Table 6, AIC reaches the minimum at the fourth order of lag, while SC reaches the minimum at the first order of lag, so the optimal lag order can't be determined only by AIC criterion and SC criterion. Referring to other statistics, we find that LR and FPE reached the minimum at the first order of lag. That is, when the lag order is one, the SC, LR, and FPE values synchronously reach a minimum. Therefore, the optimal lag order was selected as the first order of lag.

On the other hand, we have conducted unit root tests and the results show that the first-order difference is stationary. Therefore, we can use the OLS method to estimate the parameters of the VAR model. Finally, the following VAR (1) model was established.

$$\begin{bmatrix} LNUR_t \\ LNIND_t \\ LNINF_t \\ LNAG_t \end{bmatrix} = \begin{bmatrix} 0.59 & 1.04 & 0.25 & 0.47 \\ -0.07 & 0.10 & -0.07 & -0.16 \\ 0.11 & -0.11 & 0.24 & -0.18 \\ 0.39 & -0.01 & 0.33 & 0.50 \end{bmatrix} \times \begin{bmatrix} LNUR_{t-1} \\ LNIND_{t-1} \\ LNINF_{t-1} \\ LNAG_{t-1} \end{bmatrix} + \begin{bmatrix} -0.06 \\ 1.76 \\ -0.16 \\ -0.02 \end{bmatrix}$$

TABLE 3. The results of the unit root test.

Variable	Test Type	The ADF Statistic	Critical Value 0.01	0.05	0.10	Probability	Conclusion
LNUR	(c, 0, 0)	-1.216	-3.788	-3.021	-2.650	0.64	Unstable
LNIND	(c, 0, 0)	-2.229	-3.788	-3.012	-2.646	0.20	Unstable
LNINF	(c, 0, 0)	0.123	-3.788	-3.012	-2.646	0.95	Unstable
LNAG	(c, 0, 1)	0.919	-3.809	-3.021	-2.650	0.76	Unstable
ΔLNUR	(c, t, 0)	-8.600	-4.498	-3.658	-3.269	0.00***	Stable
ΔLNIND	(c, 0, 2)	-4.044	-3.857	-3.040	-2.661	0.01***	Stable
ΔLNINF	(0, 0, 0)	-2.270	-2.686	-1.960	-1.607	0.03**	Stable
ΔLNAG	(c, 0 ,0)	-5.890	-3.809	-3.021	-2.650	0.00**	Stable

Notes: 1. 'Δ' denotes a first-order difference calculation for a variable. 2. The ADF test type is (c, t, k), where c denotes the intercept term, t denotes the trend term, and k represents the lag order. 3. '**' and '***' signify the 5% and 1% significance levels, respectively.

TABLE 4. The results of the cointegration test.

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.892015	84.06426	40.17493	0.0000
At most 1 *	0.655280	39.54897	24.27596	0.0003
At most 2 *	0.596374	18.24853	12.32090	0.0046
At most 3	0.005147	0.103201	4.129906	0.7916

TABLE 5. The results of the Cointegration equation model test.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNUR	0.518710	0.109399	4.741452	0.00***
LNIND	0.124160	0.061750	2.010693	0.06*
LNINF	0.417266	0.089237	4.675909	0.00***
C	-0.269761	0.145630	-1.852365	0.08*
R-squared	0.993658	Mean dependent var		4.022468
Adjusted R-squared	0.992601	Akaike info criterion		-3.645340
F-statistic	940.0803	chwarz criterion		-3.446968
Prob(F-statistic)	0.000000	Durbin-Watson stat		1.546653

Note: '*', '**' and '***' signify significance at the 10%, 5% and 1% levels, respectively.

4) GRANGER CAUSALITY TEST

After determining the optimal lag order, the VAR (1) model was constructed, and the Block Exogeneity Wald Tests method was used to perform the Granger causality test on the model [55]. The results are presented in Table 7.

The Granger Joint Test results showed that the combined effect of the development of any three modernization is the Granger reason for the other. In other word, the combined effect of urbanization, industrialization, and informatization was the Granger reason for the development of agricultural modernization. The combined effects of agricultural modernization, urbanization, and informatization were the Granger reason for the development of industrialization. The collective impact of urbanization, agricultural modernization, and informatization was the Granger reason for the development of industrialization. The combined effects of industrialization, informatization, and agricultural modernization were the Granger reason for the development of urbanization. The empirical results show that China's new urbanization, industrialization, informatization, and agricultural modernization are an organic whole that integrates and influences each other, which is consistent with our previous theoretical analysis of the interaction mechanism.

The single equation Granger test showed that urbanization was the Granger reason for the development of agricultural modernization, but agricultural modernization was not the Granger reason for the development of urbanization. The development of urbanization and the development of industrialization were Granger reasons for each other. Industrialization was the Granger cause of informatization; however, the opposite was invalid. Agricultural modernization was the Granger reason for the development of informatization, but the opposite was not true. This is consistent with the actual situation in China. The rapid progress of urbanization has increased the demand for surplus labor in rural areas, and farmers are constantly flocking to cities, resulting in an increase in farmers' income, living standards, and degree

TABLE 6. The selection of optimal lag order for VAR models.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	31.92171	NA	0.000123	-3.324634	-3.225704	-3.310993
1	86.72826	91.34426*	4.39e-07*	-8.969807	-8.673016*	-8.928883
2	89.56271	4.094197	5.11e-07	-8.840301	-8.345650	-8.772095
3	93.98786	5.408523	5.16e-07	-8.887540	-8.195029	-8.792052
4	99.52024	5.532374	4.86e-07	-9.057804*	-8.167432	-8.935034*

TABLE 7. The Granger causality test results of the VAR (1) Model.

variable	Null Hypothesis	statistics	df	Prob.
LNUR	LNAG is not the Granger reason for LNUR	0.021	1	0.884
	LNINF is not the Granger reason for LNUR	0.830	1	0.362
	LNIND is not the Granger reason for LNUR	3.577	1	0.059*
	LNAG, LNINF, LNIND is not the Granger reason for LNUR	8.766	3	0.033**
LNIND	LNAG is not the Granger reason for LNIND	0.404	1	0.525
	LNUR is not the Granger reason for LNIND	7.398	1	0.007***
	LNINF is not the Granger reason for LNIND	0.190	1	0.663
	LNAG, LNUR, LNINF is not the Granger reason for LNIND	12.352	3	0.006***
LNINF	LNAG is not the Granger reason for LNINF	3.989	1	0.046**
	LNUR is not the Granger reason for LNINF	1.386	1	0.239
	LNIND is not the Granger reason for LNINF	5.664	1	0.017**
	LNAG, LNUR, LNIND is not the Granger reason for LNINF	16.775	3	0.000***
LNAG	LNUR is not the Granger reason for LNAG	14.938	1	0.000***
	LNINF is not the Granger reason for LNAG	0.450	1	0.502
	LNIND is not the Granger reason for LNAG	1.661	1	0.198
	LNUR, LNINF, LNIND is not the Granger reason for LNAG	15.273	3	0.002***

Note: '*', '**' and '***' signify that the null hypothesis is rejected at the 10%, 5%, and 1% significance levels, respectively.

of agricultural mechanization, greatly promoting the development of agricultural modernization. However, although agricultural modernization has made progress, its impact on urbanization development is limited.

5) IMPULSE RESPONSE FUNCTION

The impulse response function describes the impact of one endogenous variable on other variables in the VAR (1) model. According to the Granger test result of the VAR (1) model, an impulse response function can be used to analyze the response styles between the variables with Granger causality. Figure 3(A) shows the impulse response of new urbanization (LNUR) to new industrialization (LNIND). If a positive impact were applied to LNIND, the LNUR would reach the fastest response speed in the second period. Then the response speed declines, finally rises slowly, and remains stable, which will be positive after the sixth period. According to Figure 3(B), if a positive impact is applied to the LNUR, the response speed of LNIND reaches its maximum in the second period. The response index will slowly increase and finally remain stable. This shows that new urbanization and new industrialization will respond quickly after being affected by each other and this response is persistent and positive. However, new urbanization will have a more significant and lasting impact on the new industrialization. Figure 3(C) shows the impact of a change in the standard deviation of LNIND on

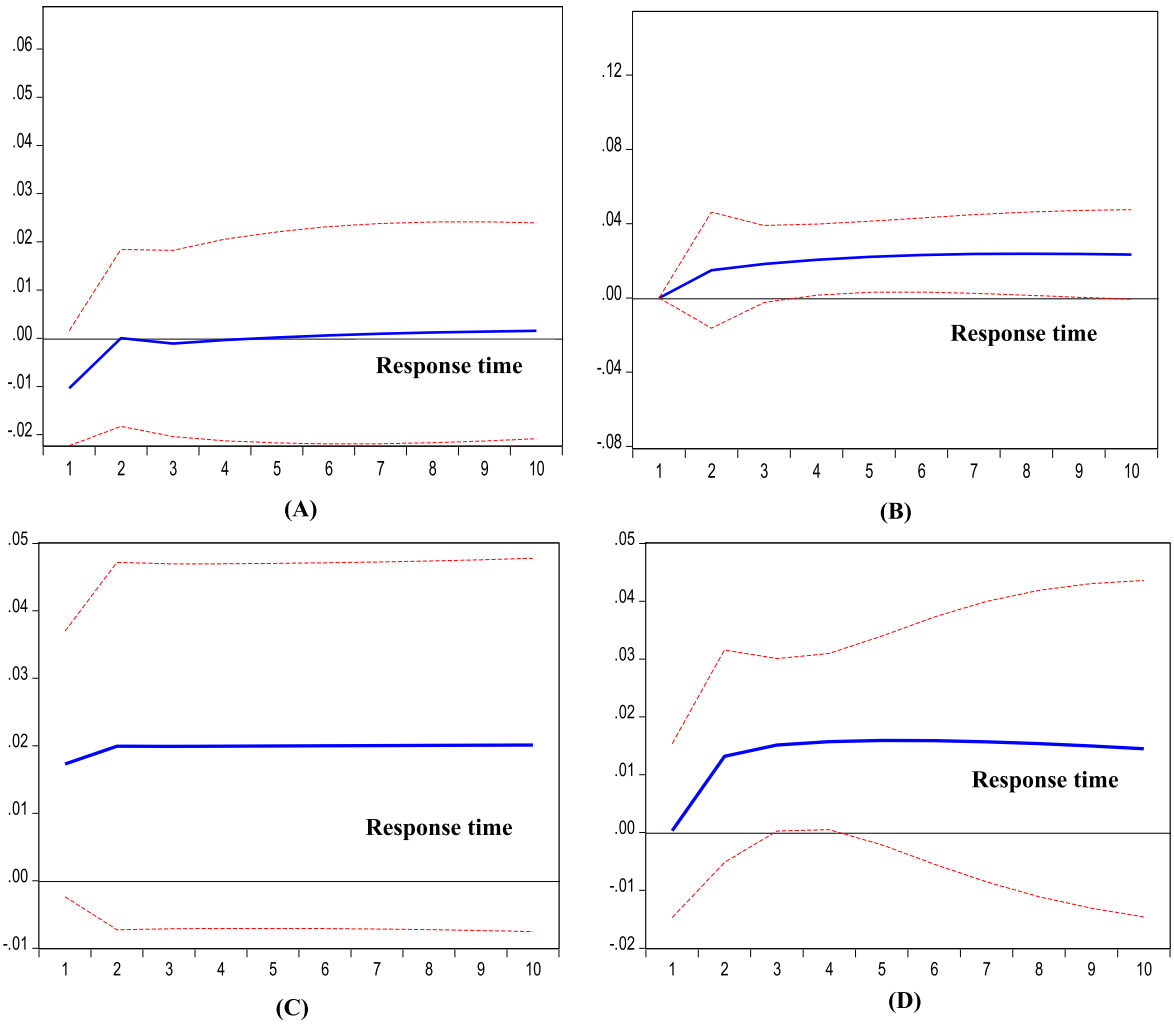

FIGURE 3. Impulse response curve. (A) Response of LNUR to LNIND; (B) Response of LNIND to LNUR; (C) Response of LNINF to LNIND; (D) Response of LNINF to LNAG.

LNINF. The change of the variable LNIND positively impacts LNINF. The response speed began to remain stable after reaching its maximum in the second period, indicating that the impact of LNIND on LNINF was persistent and positive. Figure 3(D) shows the effect of a change in the standard deviation of LNAG on LNINF. The impact of the change of the variable LNAG on LNINF was initially zero, and the response speed reached its maximum in the second period. Subsequently, the force increases slowly and finally remains stable. This shows that the impact of LNAG on LNINF is rapid, lasting, and positive.

In short, new urbanization and industrialization are mutually reinforcing. New urbanization development provides talent, capital and markets for industrialization. On the other hand, the development of industrialization can promote urban residents' employment and improve the living standards of urban residents, providing support for urbanization. However, the promotion effect of new urbanization on industrialization is stronger, which is determined by the special situation of urbanization in China. Led by the government, deeply involved in the market, and bundled with education and medical care, China's urbanization has attracted a large number of people, capital, and good supporting infrastructure in a short period of time, providing conditions for the long-term development of industrialization. Second, industrialization has a long-term positive impact on informatization development. With the development of China's industrialization, under the requirements of optimizing industrial structure and high-quality development, new industries such as industrial informatization, intelligent manufacturing, and industrial Internet continue to emerge, providing new opportunities for informatization development. Finally, agricultural information, rural e-commerce, and the improvement of farmers' living standards also have a huge demand for informatization, so agricultural modernization has a lasting positive impact on informatization.

6) VARIANCE DECOMPOSITION

Based on the above VAR (1) model and Granger joint test results, the combined effect of the development of any three

TABLE 8. The variance decomposition results of the VAR (1) model.

Period	Variance Decomposition of LNIND				Variance Decomposition of LNUR			
	LNIND	LNUR	LNAG	LNINF	LNIND	LNUR	LNAG	LNINF
1	100.000	0.000	0.000	0.000	5.293	94.707	0.000	0.000
2	94.622	3.484	1.711	0.183	3.394	95.981	0.053	0.572
3	92.224	5.897	1.679	0.201	2.423	96.080	0.078	1.419
4	89.498	8.614	1.629	0.259	2.040	95.607	0.181	2.172
5	86.621	11.436	1.583	0.359	1.864	94.984	0.324	2.828
6	83.722	14.233	1.549	0.496	1.782	94.345	0.480	3.393
7	80.908	16.905	1.528	0.659	1.744	93.742	0.636	3.878
8	78.252	19.391	1.519	0.837	1.730	93.192	0.783	4.295
9	75.796	21.662	1.520	1.022	1.728	92.701	0.919	4.652
10	73.558	23.709	1.529	1.204	1.733	92.265	1.042	4.960
Period	Variance Decomposition of LNAG				Variance Decomposition of LNINF			
	LNIND	LNUR	LNAG	LNINF	LNIND	LNUR	LNAG	LNINF
1	10.455	15.524	74.021	0.000	0.697	16.086	2.662	80.556
2	9.303	30.103	60.165	0.428	1.755	12.481	14.458	71.306
3	7.268	44.427	47.902	0.404	1.671	21.197	17.082	60.049
4	5.688	56.756	37.178	0.378	1.302	36.488	15.155	47.054
5	4.582	65.796	28.993	0.629	1.015	51.487	11.941	35.557
6	3.841	71.970	23.111	1.078	0.882	62.915	9.102	27.100
7	3.349	76.084	18.957	1.610	0.860	70.690	7.038	21.413
8	3.020	78.821	16.011	2.148	0.895	75.761	5.642	17.702
9	2.797	80.656	13.891	2.655	0.955	79.041	4.722	15.282
10	2.643	81.900	12.341	3.115	1.022	81.174	4.118	13.686

modernizations was the Granger reason for the other. Such specific causality can be analyzed using the differential decomposition theory, whose core idea is to calculate the contribution of different variables (usually measured by variance) to the fluctuations of a certain variable in the system when it is structurally impacted. The results of the variance decomposition of each variable of the VAR (1) model are shown in Table 8.

First, new industrialization carried a 100% impact in the initial period and gradually declined. However, it continued to play a significant role in the tenth period. New urbanization had the most significant contribution rate to new industrialization, reaching 23.709% in the tenth period. The contribution rate of agricultural modernization and informatization was minimal at 1.529% and 1.204%, respectively, in the tenth period. Due to the large scale, complete categories, and complex system of China's industry, it has a certain degree of stability and can withstand long-term impacts on its own after being hit. But this also indicates that only long-term persistence can achieve industrial structure upgrading and high-quality industrialization development. On the other hand, urbanization is the carrier of industrialization and has a comprehensive and profound impact on the development of industrialization. Consequently, urbanization still significantly affects industrialization in the long run.

Second, new urbanization carried a 94.707% impact in the initial period. It then showed a downward trend but continued to bear most of the impact of 92.625% in the tenth period. The contribution rate of new industrialization to new urbanization decreased from 5.293% in the initial stage to 1.733%. The contribution rates of agricultural modernization and informatization rose steadily from 0 to 1.042% and 4.960%, respectively. The construction of urbanization is a cumulative long-term process, and its urban system has a

certain degree of stability. Therefore, after being hit, it can only rely on itself to bear the long-term impact.

Third, after the impact of agricultural modernization, it took most of the impact (74.021%) in the initial stage, and urbanization and industrialization respectively took part of the impact. In the later period, urbanization contributed the most to agricultural modernization, reaching 81.9%. Due to the direct material basis provided by agricultural modernization for urbanization and industrialization, the impact on urbanization and industrialization becomes apparent immediately in the early stages after being affected. At the same time, the close connection between urbanization and agricultural modernization in terms of population and geography has made urbanization an important long-term influencing factor for agricultural modernization. However, the development of agricultural information in China is insufficient, and the integration of agricultural modernization and informatization is insufficient. Therefore, the impact of informatization on agricultural modernization is very limited.

Fourth, new informatization carried most of the impact in the initial stage, and new urbanization brought a more significant impact. However, in the later period, the contribution rate of new urbanization to new informatization reached an astonishing 81.174%. Informatization occurs when industrialization reaches a certain stage. China's informatization development level is relatively weak, and it is mainly concentrated in urban areas. Urbanization and informatization are deeply integrated, such as smart cities. Therefore, when informatization is affected, it will have an immediate impact on industrialization and urbanization, and urbanization contributes the most to the long-term impact.

V. CONCLUSION AND DISCUSSIONS

A. CONCLUSIONS

This study theoretically analyzed the interaction mechanisms of new urbanization, industrialization, informatization and agricultural modernization. We then constructed an index system for the development level of new urbanization, industrialization, informatization, and agricultural modernization, and used principal component analysis to measure the development level of China's NFM over the years. Finally, VAR model was built according to the comprehensive evaluation results, and the interaction effect was further analyzed in detail. According to empirical research results, the following basic conclusions were drawn:

(1) The comprehensive evaluation results showed that China's new urbanization, industrialization, informatization, and agricultural modernization were rising. The overall development level of informatization and agricultural modernization was lower than that of urbanization and industrialization. The fluctuation of industrialization development was significantly higher than that of the other three.

(2) The cointegration test showed a long-term equilibrium relationship between the development of new urbanization, industrialization, informatization, and agricultural modernization. In the long run, new urbanization, informatization, and industrialization had a positive impact on the development of agricultural modernization. New urbanization had the most significant effect on agricultural modernization, followed by informatization and industrialization had the least effect.

(3) From a macro perspective, the Granger joint test found that the combined effects of any three developments in new urbanization, industrialization, informatization, and agricultural modernization had a significant causal relationship with the development of the other. This shows that new urbanization, industrialization, informatization, and agricultural modernization are organically interconnected and interacts with each other. The synchronous development of the NFM has an inherent driving force. Therefore, this empirical conclusion is consistent with the theoretical analysis.

(4) The interaction relationship from the micro perspective showed that new urbanization and new industrialization were granger causes for each other's development. Still, the impact of urbanization on industrialization was more significant than industrialization on urbanization. Industrialization and agricultural modernization were granger causes of informatization development, while new urbanization was the granger cause of agricultural modernization development. Moreover, this influence has the characteristics of rapid response, continuous effect, and positive results.

(5) According to further analysis of variance decomposition, it can be seen that the long-term impact of new urbanization and industrialization was mainly carried by itself. The contribution rate of new urbanization to informatization and agricultural modernization was the largest, which exceeds their own contribution rate.

B. DISCUSSIONS

Since the beginning of the 21st century, China's society and economy have developed rapidly, and its total economic volume has steadily ranked second in the world. New urbanization, industrialization, informatization and agricultural modernization are important aspects of China's modernization construction, which is an inevitable choice to promote sustainable, stable, and healthy development of social economy. Based on the results of empirical research, this article discusses the development and interactive mode of China's new urbanization, industrialization, informatization, and agricultural modernization, with the aim of providing Chinese experience for other countries in the world (especially developing countries).

According to the experiences of developed countries, industrialization is the main driving force of urbanization [56]. Many enterprises are attracted by the advantages of geographical location, transportation conditions, and

resource endowments. In this process, industries and populations are gathered, leading to urbanization and promoting the development of informatization and the modernization of surrounding agriculture. This is a natural path with the characteristics of spontaneity and slowness.

The Chinese model is different. Under market forces, government-led urbanization was the core factor in industrialization, informatization, and agricultural modernization. The specific path to attract the population was that the government formulates urban development plans, transfers land to real estate enterprises for residential development, and improves supporting measures for infrastructure, medical care, and education. In this mode, cities and towns with complete supporting facilities were first established, and industrial chains and industrialization were formed. The capital, talents, and market advantages of cities and towns further support informatization and agricultural modernization. This model has a pronounced effect on promoting social development and economic growth in the early stages of urbanization. The empirical results of this study also support these views.

However, there are some problems with this Chinese model [35]. For the sake of its political achievements, the government has blindly expanded the scale of towns, repeated demolition and construction of infrastructure, and unreasonable town planning. This has led to problems such as empty ghost towns (population, industrial agglomeration failure), waste of resources, housing price bubbles, environmental pollution etc. From the perspective of the objective law of development, the development speed of new urbanization in the middle and late stages will inevitably decline. The role of urbanization in promoting the development of industrialization, informatization, and agricultural modernization may not be influential. China's seventh census in 2021 shows that its urbanization rate has reached 63.89%. Scholars generally believe that China's urbanization has reached the mid-term stage, and that some regions have entered the mid-to-late stage of urbanization. Although urbanization has made great contributions to Chinese modernization, its effect on new industrialization, informatization, agricultural modernization and economic growth will be very limited in the post urbanization period.

The above conclusions and discussions were significant for us to correctly understand the development status and interaction mechanism of China's NFM. Taking China as an example, we can answer the three questions mentioned above. First, the strategy of NFM synchronous development has a certain theoretical basis and practical evidence, as confirmed by this study. Second, the NFM synchronous development has an internal driving force, as shown in Conclusion (3). Third, new urbanization plays a core role in the synchronous development of NFM in China, regardless of long-term equilibrium or short-term impact. However, in the long-term equilibrium and short-term impact, the positions and roles of new industrialization, informatization and agricultural modernization in the synchronous development of the NFM were different, as shown in conclusions (2), (4), and (5).

VI. POLICY RECOMMENDATIONS

Based on the above conclusions and discussions, we have gained a profound understanding of the current development status, interactive models, and existing problems of China's new urbanization, industrialization, informatization, and agricultural modernization. We therefore made the following policy recommendations:

First, developing countries can learn from the Chinese experience and model. They should give priority to urbanization and promote the development of industrialization, informatization and agricultural modernization through population agglomeration, infrastructure construction and industrial policies, which can achieve rapid social and economic development at the initial stage.

Second, the follow-up development of China's new urbanization and industrialization should establish the concept of ecological civilization and pay more attention to urbanization quality and industrialization benefits. On the one hand, the government should strengthen public services such as urban health care, education and public transport, placing social urbanization and ecological urbanization in the important position of new urbanization. On the other hand, the Chinese government should optimize the upgrading of the industrial structure, promote informatization to empower the development of industrialization, and rely on innovative elements to drive economic growth. Targeted tax cuts can also be considered to guide capital flows into environmental protection industries and high-tech enterprises.

Third, local governments should adapt measures to local conditions to create an environment for the rapid development of informatization and agricultural modernization. We should encourage the development of e-commerce, "Internet +" and other emerging industries to break the monopoly of information service industry, reducing information services cost. On the other hand, the government should encourage areas suitable for large-scale mechanized agricultural production to accelerate land transfer and increase investment in rural areas and agriculture. Finally, in view of the unbalanced and uncoordinated regional development of China's NFM, the central government should appropriately tilt towards the central and western regions in terms of policies and capital. For example, we can consider the establishment of free trade zones in countries bordering western China to create new highlands for China to open.

VII. LIMITATIONS AND FUTURE STUDY

Research in this study is still inadequate. Inspired by this paper, it was conjectured that the interaction between urbanization, industrialization, informatization, and agricultural modernization was universal at the macro level, which had nothing to do with the region. However, the interaction at the micro level depends on the development path model of the region. Limited by the content, purpose and length of this study, this conjecture has not been confirmed, and much work may be needed for further in-depth studies with new methods and ideas. Specifically, we can choose typical countries or

regions (such as developed countries, developing countries, large countries, small countries, etc.) to study the interactive models of new urbanization, industrialization, informatization, and agricultural modernization. On the other hand, new methods such as comparative analysis, heterogeneity analysis and panel data analysis can be considered to verify the conjecture of the NFM interaction mode. In short, this study is just a throwing stone to start, and supports the above conjecture to some extent, but the evidence is still insufficient. Future research must adopt a comprehensive analytical approach from multiple perspectives and employ diverse methodologies to acquire reliable and profound conclusions.

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