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Industrial integration and value creation: a three-sector production function approach

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The extension of agricultural industry to manufacturing and service industry is the development direction of the rural industrial integration. Empirical evidence demonstrates that industrial chain extension and reinforcement significantly enhance value creation. This research examines how industrial integration influences the value-added processes of the industrial chain, focusing on agricultural industry transformation. We discuss the industrial integration and its impact on value creation using a combination of theoretical and empirical methods. We develop a three-sector production function by extending the classical two-sector function. Empirical analysis verified the consistency with the theoretical model from both Chinese data and international experiences. The results represent that the integration model, planting structure, and factor productivity have elastic effects on the industrial chain's value creation. ①The agricultural industry exerts a significant spillover effect on the manufacturing industry, and the manufacturing industry, in turn, has a markedly substantial spillover effect on the service industry. ②Factors marginal productivity in the agricultural and manufacturing industries is higher than that of the service industry. ③The integration model, the planting structure, and the quality of input factors exert significant external impacts on the industrial chain's value creation. ④There are structural contradictions and regional imbalances in industrial integration. These findings suggest that optimizing the structure of agricultural production, promoting manufacturing, and fostering technological progress can create industrial chain value and support high-quality industrial development.

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Introduction

Background. Achieving high-level integrated development of industries requires the support of the agricultural sector. It is even more necessary to take advantage of industrial integration to achieve coordinated development of multiple industries. Therefore, integrating the entire industrial chain to promote value chain appreciation is a critical way to achieve high-quality development of the industrial economy. This study has significant implications for industrial structure and industrial chain.

Industrial integration promotes industry structural transformation. Developed countries have experienced the transition from the primary industry-oriented to the secondary and tertiary industries-oriented. The development structure of the three major industries in China also presents specific “Simon Smith Kuznets Facts” (Chen, 2007), just like what developed countries have experienced. “Simon Smith Kuznets Facts” stated that the evolutionary laws of economic growth and structural transformation. It is believed that changes in industrial structure are caused by technological progress, capital accumulation, and institutional reform, which further lead to differences in factor productivity among the three industries. This is consistent with our research objectives. Following the logic of “factor productivity” to “industrial structure” and then to “economic growth”. We analyzed the path from “factor productivity” to “rural revitalization”. We establish the correlation between “factor productivity” and “industrial chain value creation” from the perspective of industrial integration using three-sector production function model. The industrial chain can drive agricultural value creation and achieve rural revitalization.

In the long run, Chinese urban-rural “Dual-structure”¹ has caused industrial structure disequilibrium, intensified urban-rural interest conflicts, and hindered economic structure adjustment and optimization (Liu, 2018). Similarly, Montalbano and Nenci (2022) stated that the agricultural added value is positively correlated with the global value chain. The report of the 19th National Congress of the Communist Party of China (CPC) stated that “The problems of Agriculture, Rural areas and Farmers (the “ARF” problems) are the fundamental problems concerning the national economy, and the whole country should always give top priority to solving the ARF problems”. The rural revitalization strategy is the succession and development of principles and policies. One of the general requirements of the rural revitalization strategy is to promote industrial development, guide and attract more capital inflows, like technology development, human resources, and other factors. In addition, it stimulates the enthusiasm and creativity of farmers to form a modern industry system. Also, it enhances industry integration development to maintain the vigorous growth of the agricultural and rural economies. The deployment of a rural revitalization strategy relies on the reform drive, promoting agricultural and rural modernization and achieving urban-rural coordination. The policy is to encourage the sustained high-speed growth of industrial economy by reallocating pastoral resources and sharing the welfare of industrial integration (Cai, 2019).

Industrial integration promotes the development of the industrial chain. It is an essential deployment to promote rural revitalization through the primary-secondary-tertiary industries integration. To encourage the transition and upgrading of industry structures, it is vital to effectively implement strategies, such as allocating agricultural and rural resources, stimulating input of factors in modern agriculture, and implementing the integrated industrial growth mode with native characteristics (Jiang, 2017). Accelerating traditional industry optimization and linking small-scale farmers with modern agriculture is crucial. We promote industry integration by enhancing the interest linkage mechanism and leveraging system, technology, and business

model innovations. Industry integration is based on agriculture, which extends the industrial chain, upgrades industrial functions, and enhances the efficiency of cross-border allocation of factors to achieve organic integration, such as manufacturing, leisure tourism, and other services. Industrial integration emphasizes the transformation of traditional agriculture with the input of modern factors to promote agricultural modernization and the coordinated development of various industries, promoting high-quality industrial chain development (Subject group of Macro Institute and Department of Agricultural Economics, National Development and Reform Commission, 2016).

Research gap. Focusing on the goal of “letting the primary-secondary-tertiary industry upgrade and benefit from integration”, this paper explores the relationship between industrial integration and industrial chain value creation. Aiming at the realistic problem, the integration promotes the high-quality development of the industrial chain. The scientific problem is to research the impact of the industrial chain extension and upgrading. We lack some key steps for the research. ①The classic two-sector production function model cannot meet the needs of three-sector integration. ②The correctness of mathematical function models still needs to be verified by empirical data, and the data is scattered and complex, requiring a lot of time to organize. ③Theoretical and practical experience also requires the support of international experience. ④The way relying on the input of resources to promote economic growth is not feasible, and high-quality development must rely on innovation in production methods and institutions.

Through theoretical and empirical analysis, the study seeks to uncover how changes in integration models, planting structures, and factor productivity affect industrial chain value creation. The planting structure is defined as the circulation process of primary agricultural products, which refers explicitly to the composition of the agricultural products used for manufacturing or direct consumption. Improving factors quality and optimizing agricultural industry structure are essential for integration. Relying on industrial integration, improving the quality of input new factors, and achieving breakthrough growth are the leading forces in leaping over the low-speed development stage. We explore the answer to the practical problem of industrial economic development from the scientific research question of the “long-chain system”. The study will contribute strategies to high-quality development of the industrial chain.

Innovation and contributions. ①We consider the sector’s internal correlation and external impact and pursue the sector’s cooperation effect to increase value. ②The research follows the logical basis of “factor productivity improvement”, “industrial structure transformation”, and “economic growth”, and also considers variables such as industrial chain integration mode and agricultural production structure. Industrial integration guides the coordinated development of the entire industrial chain. ③The research expands the two-sector production function model, constructs the three-sector integration production function model, and uses it for empirical analysis to explore the general law of industrial integration and high-quality development of the industrial chain. The research combines mathematical models and empirical analysis, which contribute to the application.

Brief methodology overview. Our research follows this process: ①We construct a production function model that integrates three sectors, test the model, and simulate the policy by analyzing Chinese inter-provincial panel data from 2004 to 2020. ②We

analyze the specific facts on the world's rural industry structure transformation by using the data from 32 non-oil-exporting countries from 1980 to 2016. ③We compare the changes in the internal structure of the agricultural industry in developed and developing countries. ④The general law of agricultural industry structure transformation and economic development is summarized.

Theoretically, three-sector production function model is constructed to describe the impact of integration model, planting structure, and factors productivity in the industrial chain. The output growth rate of the industrial chain refers to the elasticity of the output growth of the industrial chain and directly affects the output scale of the industrial chain, which is defined as increased industrial chain value. We use empirical data to analyze industrial chain high-quality development, focusing on three aspects: optimizing integration models, planting structures and factors productivity.

Literature review

Scholars have proven that industrial structural transformation requires improving factor productivity and institutional innovation. Thus, we review relevant literature from three perspectives: production functions, key factors driving economic growth, and factors spillover effects.

Production function and application. The production function model provides a valuable tool for economic management (Cobb and Douglas, 1928; Solow, 1956; Sato, 1967; Feder, 1983). It is divided into two models based on different research objectives.

- (1) Development of production function model. One is the single-sector model, like the constant elasticity of substitution (CES) model and the variable elasticity of substitution (VES) model derived from the *Cobb-Douglas production function*. It mainly examines how key input factors (e.g., labor, capital, technology) affect sectoral output. The other is the two-sector model, typified by the *Feder model* with various improved forms. It builds a two-sector production function based on the single-sector model.
- (2) Application of production function model. The two-sector model is used to study the external effects of input factors and the impact of different factors on sectors productivity. Compared with the single-sector model, the two-sector model has a more vital ability to explain the real world. Acemoglu and Guerrieri (2008) used a two-sector general equilibrium model to propose the unbalanced productivity growth model based on factor proportion differences and capital deepening. Capital deepening boosts capital-intensive sectoral relative output and causes capital and labor outflow. This result was consistent with *Kalodr's facts*, especially in less capital-intensive industries. Duarte, Restuccia (1928) explored Portugal's industrial structure transformation essence by analyzing agricultural labor redistribution into manufacturing and service industries. They found that agriculture and service industries had lower productivity rates. In contrast, the manufacturing industry showed a rapid growth trend and narrowed the gap with the total factor productivity of the United States. Some scholars used the two-sector production function model to analyze the impacts of single-sector factors on two-sector economic growth (Liu and Liang, 2008; Sun and Tian, 2011; Su and Chen, 2014). Other scholars examined the contribution of the structural adjustment of the primary-secondary-tertiary industry to economic growth (Liu and Li, 2002; Gao and Li, 2006; Zheng and Ran, 2021).

Drivers of economic growth. Since the 1980s, there has been extensive research on the dynamic mechanism of economic growth. They focus on drivers such as total factor productivity (TFP) and labor productivity, which are generally regarded as endogenous driving forces. The deceleration and stability period in the process of economic growth can be attributed to the law of diminishing marginal returns of inputted factors, even though demographic dividend slows down the diminishing effects of capital return.

- (1) Factor dependence. Scholars represented by Lucas (1988) believed that the learning effect of human resources could be used to explain economic growth differences. Subsequently, research on economic growth has increasingly focused on its dynamic mechanism, leading to two theoretical branches that describe the economic transformation of developed and emerging economies. Technological progress or capital deepening can ultimately result in differences in sectoral productivity due to factors such as product substitution elasticity, sectoral differences in technological progress rates, and factor output elasticity (Zhang et al. 2022).
- (2) Economic transformation. The transformation of developed economies is a natural evolutionary process driven by capital accumulation and technological change (Galor and Weil, 1996; Laitner, 2000; Stocritical, 2000; Hansen and Prescott, 2002). Capital can improve the internal driving force of the agricultural industry (Hu, 2022). Undeveloped economies are transformed by technological innovation brought about by the human resources learning effect and institutional change under external effect (Goodfriend and Mcdermott, 1995; Tamura, 2002; Kejak, 2003). Profitability can be improved by innovating planting techniques to increase yields or by increasing the value of specialty crops (Torres, 2022). Lu et al. (2021) found that strengthening farm household welfare should encourage the adoption of multiple agricultural technologies in farm to realize the most welfare.
- (3) The long-term mechanism for economic growth. Romer (2004) believed that technological and institutional innovation is a long-term mechanism for economic growth, while the contribution of capital, labor, and other factors to economic growth is unsustainable. It can be seen that different production factors have different contribution mechanisms that transform different economies.

Industrial integration and economic growth. Many studies have verified the promoting effect of industrial integration on economic development, both theoretically and practically, as it deepens continuously.

- (1) Industrial integration and economic growth. Theoretically, the technological connection between industries catalyze industrial integration (Sahal, 1985). This technology-based industrial integration inevitably leads to economic growth by weakening the industrial boundary and gradually forming an extended development model that integrates products, industries, and markets (Yoffie, 1996; European Commission, 1997; Shinans, 2006).
- (2) Structure transformation and economic growth. The balanced productivity growth model highlights that redistributing a large amount of agricultural labor to industry and services and adjusting the industrial structure via factor allocation are key laws for economic growth. Moreover, the breakthrough from "Kaldor Fact" to "New Kaldor Fact" is the logical for increasing human capital investment,

improving technological innovation, and reducing resource mismatch efficiency (Cai et al. 2018). The progress of science, technology, and the change of leading industries show a certain periodicity characteristics, and the resulting “structural dividend”² is a core power of industrial structures that promotes sustainable economic growth (Baumol, 1967).

- (3) Innovation mechanism and industrial integration. Introducing new factors, transforming development mode (innovation-driven), and strengthening institutional reform are new forces to promote economic growth (Zhang, Cheng (2019)). Extending the agricultural industrial chain, upgrading the value chain, increasing farmers’ income, and optimizing input factors are the specific requirements for transforming the agricultural industry structure (Xiong, 2018). In recent years, from the perspective of agricultural industry integration, many scholars believe that the extension and upgrading of the agricultural industrial chain is one of the specific modes of agricultural industrial development, creating conditions for increasing farmers’ income and realizing the “synchronization of four modernizations” (Ma, 2015; Jiang, 2015). The representative view abroad is “Six Industries”³ defined by Nimitsu Nimura of Japan. The concept is significant for integrating and developing the primary-secondary-tertiary industry. The supply-side structural reform is to improve TFP from the supply side and create a “Reform dividend” relying on improving labor productivity (Cai, 2017).

Differences. Existing research attaches importance to the contribution of industrial structure transformation to economic growth. Mainstream scholars attribute factor productivity improvement in industry and services to industrial transformation. However, most of these conclusions are based on the separation of all or part of the three sectors. If the correlation among these three is ignored, the guiding significance of the above findings for industrial integration needs to be discussed.

We propose the differences between this study and existing literature. ①The relationship within the three sectors focuses on the supply and demand from an industrial chain input-output perspective. ②The external role of industrial sectors lies in the impact of the upstream outputs on downstream outputs, viewed from the industrial chain’s value creation perspective. Consequently, the increase in industrial chain value can only be realized by moving from agricultural production to terminal consumption.

Model and mechanism analysis

Industrial integration is categorized into two basic forms: primary-tertiary integration and primary-secondary-tertiary integration. The former involves agricultural produce being directly used for consumption, while the latter implies that agricultural output is utilized after undergoing manufacturing processes. This article reveals the impact of the integration model, planting structure, and factor productivity on industrial chain value through the production function model. For convenience, agricultural production is divided into produce for consumption and manufacturing. According to the general classification of agricultural product processing, primary processing refers to the one-time processing of agricultural products that does not involve changing the internal components of the products. Deep processing (or value-added processing) entails secondary or multiple processing stages, primarily focusing on extracting and utilizing of protein resources, lipid resources, novel nutritional resources, and bio-active components. Agricultural production intended for direct consumption or consumption following primary

processing is termed consumer-oriented production to facilitate differentiation and description. Conversely, agricultural production providing raw materials for intensive secondary industry processing is designated production-oriented production. Consequently, the integration model can simulate transforming primary agricultural products into services.

Assumptions and parameter settings. Based on the production and consumption process, we have designed three models: Model 1 (Primary-Tertiary integration, *PT*), Model 2 (Primary-Secondary-Tertiary integration, *PST*) and Model 3 (Cross integration, *CI*). We constructed the operating environment using the following five assumptions to compare the three models.

Assumption 1: Labor and technology are two independent factors of production, ignoring the correlation between the two. That is, changes in one factor will not cause changes in the other.

Assumption 2: We only consider the sector’s natural changes in internal factors (labor quality and technological level), ignoring the factors’ transfers between sectors (labor mobility or technology spillover). Therefore, the two industries will differ in labor and technology marginal productivity.

Assumption 3: We focus solely on the marginal productivity difference between labor and technology of two sectors, without considering the marginal productivity difference between labor and technology.

Assumption 4: We assume that the production function of the same sector remains unchanged under different models, meaning that the output functions of each industry are only related to the input factors.

Assumption 5: All the output from the previous sector is transferred to the next sector as input material without any reverse flow or loss. Therefore, the previous sector’s output value influences the next sector’s input and output value.

Based on the classical production function model, the variables and parameters (as shown in Table 1) are introduced to describe the impact of factors on industry chain value.

Model 1: industry integration of primary-tertiary (PT). Agriculture, as the basis of industry economic development, typically integrates primary and tertiary industries. This integration enables the service industry to drive agricultural growth through innovative modes and formats, like tourism, leisure, and vacations. We constructed a primary-tertiary (PT) industry integration model to simulate agricultural products directly entering the service industry without manufacturing. Thus, the industrial chain output function (Y) comprises the agricultural output from the primary sector (P) and the consumption output from the tertiary sector (C). Based on the correlation between these two sectors, where the production of sector P serves as the input to sector C , we obtain the output function as follows:

$$Y_P = f(L_P, T_P); Y_C = h(L_C, T_C, Y_P) \quad (1)$$

$$Y_I = Y_P + Y_C \quad (2)$$

Formula (1) shows that the output in sector P affects the output in sector C . Where, Y_P and Y_C are the outputs in sector P and sector C . Y_I is the output of industrial chain. L is the labor factor, T is the technology, which satisfy these two conditions: $L_I = L_P + L_C$ and $T_I = T_P + T_C$, this means that the input factors of labor and technological only includes the input of these two sectors. Under the *General Equilibrium Hypothesis*, the marginal productivity of labor, technology, and other factors in the two sectors satisfy the following conditions:

$$f'_{L_P}/h'_{L_C} = f'_{T_P}/h'_{T_C} = 1 + \delta_{13} \quad (3)$$

Table 1 Variable and parameter settings.

Symbol	Variable or parameter	Symbol	Variable or parameter	Symbol	Variable or parameter
Y_P	primary sector's output	L	labor factor investment	α_{ij}	external elasticity effect between sectors
Y_M	secondary sector's output	T	technical factor investment	θ	the proportion of agricultural output used for manufacturing
Y_C	tertiary sector's output	L_{ir}	labor factor investment growth rate of model i		
Y_{Pr}	the growth rate of primary sector's output	T_{ir}	technical factor investment growth rate of model i	Y_i	industrial chain output of the model i
Y_{Mr}	the growth rate of secondary sector's output	δ_{ij}	the difference in marginal productivity between sectors	Y_{ir}	industrial chain output growth rate of the model i

Where, $i = [1, 2, 3]$ represents one of the three integration models; $j = [1, 2, 3]$, and $i \neq j$ is the other models. θ is introduced in model 3, which is the proportion of primary sector's output invested in secondary sector.

Where, δ_{13} represents the difference of marginal productivity between labor and technology in the two sectors. When $\delta_{13} < 0$, the marginal productivity in sector P is less than that in sector C . When $\delta_{13} = 0$, the marginal productivity in the two sectors is the same. When $\delta_{13} > 0$, the marginal productivity in sector P is greater than that in sector C . Formula (4) defines the output elasticity of sector P to sector C according to the definition of elasticity, where α_{13} is the external effects of sector P on sector C :

$$\alpha_{13} = \frac{dY_C/Y_C}{dY_P/Y_P} = \frac{\partial Y_C}{\partial Y_P} \frac{Y_P}{Y_C} = h'_{Y_P} \frac{Y_P}{Y_C} \tag{4}$$

We derive the full differential of Formula (2) firstly, and divide both sides of the “=” by Y_I , then substitute formulas (3) and (4) into the full differential Formula, and we obtain the Formula (5) as follows.

$$Y_{1r} = \left(\frac{\delta_{13}a_1}{1 + \delta_{13}} + \alpha_{13}a_2 \right) Y_{Pr} + a_3L_{1r} + a_4T_{1r} \tag{5}$$

Where, $Y_{1r} = dY_1/Y_1$ is the output growth rate of the industrial chain $Y_{Pr} = dY_P/Y_P$ is the output growth rate in sector P , $L_{1r} = dL_1/L_1$ is the growth rate of labor inputted in the industrial chain, and $T_{1r} = dT_1/T_1$ is the growth rate of technology inputted in the industrial chain. $a_1 = Y_P/Y_1$ is the output proportion in sector P , $a_2 = Y_C/Y_1$ is the output proportion in sector C , $a_3 = h'_{L_C}/(Y_1/L_1)$ is the labor output elasticity in sector C , and $a_4 = h'_{T_C}/(Y_1/T_1)$ is the technical output elasticity in sector C . Given other influencing factors, the main variables of the output growth rate of the industrial chain include Y_{Pr} , L_{1r} and T_{1r} .

Model 2: industry integration of primary-secondary-tertiary (PST). The manufacturing of agricultural products is necessary to create more value. The whole industry chain drives the coordinated development of agriculture and service through manufacturing agricultural products, and it is a critical way to integrate the primary-secondary-tertiary industry. Based on Model 1, we developed Model 2, a primary-secondary-tertiary industry integration model. This model describes the consumption of agricultural products after manufacturing and to forms an industrial integration of “production”, “manufacturing” and “consumption”. We designate the agricultural manufacturing sector as M . All outputs from sector P are directed to sector M , and all outputs from sector M are directed to sector C . From this setup, we derive the following output functions:

$$Y_P = f(L_P, T_P); Y_M = g(L_M, T_M, Y_P); Y_C = h(L_C, T_C, Y_M) \tag{6}$$

$$Y_2 = Y_P + Y_M + Y_C \tag{7}$$

Where, Y_P , Y_M and Y_C are the output in sector P , sector M , and sector C . Y_2 is the output of industrial chain, and the input factors satisfy these two conditions: $L_2 = L_P + L_M + L_C$ and $T_2 = T_P + T_M + T_C$. They are different from the situation in Model 1, which indicates that the input factors of labor and technology include the input of these three sectors. It is supposed that the marginal productivity of labor, technology, and other factors as follows:

$$\begin{aligned} f'_{L_P}/g'_{L_M} &= f'_{T_P}/g'_{T_M} = 1 + \delta_{12} \\ g'_{L_M}/h'_{L_C} &= g'_{T_M}/h'_{T_C} = 1 + \delta_{23} \end{aligned} \tag{8}$$

Like Formula (3), where δ_{12} is the difference of marginal productivity between sectors P and M . δ_{23} is the difference of marginal productivity between sectors M and C . The output elasticity of sector P to sector M and the output elasticity of sector M to sector C are shown in Formula (9), where α_{12} is the external effects of sector P to sector M 's output, and α_{23} is the external

effects of sector M to sector C .

$$\begin{aligned}\alpha_{12} &= \frac{dY_M/Y_M}{dY_P/Y_P} = \frac{\partial Y_M}{\partial Y_P} \frac{Y_P}{Y_M} = g'_{Y_P} \frac{Y_P}{Y_M} \\ \alpha_{23} &= \frac{dY_C/Y_C}{dY_M/Y_M} = \frac{\partial Y_C}{\partial Y_M} \frac{Y_M}{Y_C} = h'_{Y_M} \frac{Y_M}{Y_C}\end{aligned}\quad (9)$$

We divide Y_2 on both sides of the “=” after solving the total differential of Formula (7), and substitute Formulas (3), (8), and (9), then obtain the Formula (10) as follows:

$$Y_{2r} = \left(\frac{b_1 \delta_{13}}{1 + \delta_{13}} + \frac{b_2 \alpha_{12}}{1 + \delta_{23}} \right) Y_{Pr} + \left(\frac{b_3 \delta_{23}}{1 + \delta_{23}} + b_3 \alpha_{23} \right) Y_{Mr} + b_4 L_{2r} + b_5 T_{2r} \quad (10)$$

Where, $Y_{2r} = dY_2/Y_2$ is the output growth rate of the industrial chain, $Y_{Pr} = dY_P/Y_P$ is the output growth rate in sector P , $Y_{Mr} = dY_M/Y_M$ is the output growth rate in sector M , $L_{2r} = dL_2/L_2$ is the labor input growth rate of the industrial chain, and $T_{2r} = dT_2/T_2$ is the technology input growth rate of the industrial chain. $b_1 = Y_P/Y_2$ is the output proportion in sector P , $b_2 = Y_M/Y_2$ is the output proportion in sector M , $b_3 = Y_C/Y_2$ is the output proportion in sector C , $b_4 = h'_{L_C}/(Y_2/L_2)$ is the labor output elasticity in sector C , and $b_5 = h'_{T_C}/(Y_2/T_2)$ is the technical output elasticity in sector C . It can be seen that, given other factors, the main variables of the industrial chain include Y_{Pr} , Y_{Mr} , L_{2r} and T_{2r} .

Model 3: cross-integration (CI). Some of the primary sector's products are used for direct consumption without manufacturing, and the other is consumed after manufacturing. We designed Model 3 to simulate the actual situation. Two industrial chains co-exist in the Cross-integration model. We introduce $\theta (0 < \theta < 1)$ to represent the proportion of agricultural output used for manufacturing and $1 - \theta$ is the proportion of agricultural output directly used for consumption. Therefore, we define $\theta (0 < \theta < 1)$ as the planting structure. Then, the output function of each sector and the production of the industrial chain are as follows:

$$Y_P = f(L_P, T_P); Y_M = g(L_M, T_M, \theta Y_P); Y_C = h(L_C, T_C, (1 - \theta) Y_P + Y_M) \quad (11)$$

$$Y_3 = Y_P + Y_M + Y_C \quad (12)$$

Formula (11) shows that the output θY_P represents that θ part of the output from sector P is invested in sector M , which affects the output of Y_M . Similarly, $(1 - \theta) Y_P$ represents that $1 - \theta$ part of the output from sector P is invested in sector C , which affects the output Y_C together with Y_M . Factors inputted satisfy the two conditions: $L_3 = L_P + L_M + L_C$ and $T_3 = T_P + T_M + T_C$, which is the same as Model 2. Like the calculation process of Model 2, we divide Y_3 on both sides of the “=” after solving the total differential of formula (12), and substitute Formulas (3), (4), (8) and (9), then, obtain the Formulas (13) as follows.

$$Y_{3r} = \left(\frac{c_1 \delta_{13}}{1 + \delta_{13}} + \frac{c_2 \theta \alpha_{12}}{1 + \delta_{23}} + c_3 (1 - \theta) \alpha_{13} \right) Y_{Pr} + \left(\frac{c_4 \delta_{23}}{1 + \delta_{23}} + c_3 \alpha_{23} \right) Y_{Mr} + c_4 L_{3r} + c_5 T_{3r} \quad (13)$$

Where, $Y_{3r} = dY_3/Y_3$ is the output growth rate of the industrial chain, $Y_{Pr} = dY_P/Y_P$ is the output growth rate in sector P , $Y_{Mr} = dY_M/Y_M$ is the output growth rate in sector M , $L_{3r} = dL_3/L_3$ is the labor input growth rate of the industrial chain, and $T_{3r} = dT_3/T_3$ is the technology input growth rate of the industrial chain. $c_1 = Y_P/Y_3$ is the output proportion in sector P , $c_2 = Y_M/Y_3$ is the output proportion in sector M , $c_3 = Y_C/Y_3$ is the output proportion in sector C , $c_4 = h'_{L_C}/(Y_3/L_3)$ is the labor output elasticity in sector C , and $c_5 = h'_{T_C}/(Y_3/T_3)$ is the

technical output elasticity in sector C . Therefore, given other factors, the main variables include Y_{Pr} , Y_{Mr} , L_{3r} and T_{3r} .

Integration model analysis. The three models illustrate the theoretical impact of integration model (PT, PST and CI), planting structure ($\theta (0 < \theta < 1)$), and the quality of inputted factors (L , T) on the output growth rate of the industrial chain. The output growth rate of the industrial chain refers to the elasticity of the output growth, which directly affects the output scale of the industrial chain. In the paper, the growth of industrial chain output is defined as the increase of industrial chain value, and the logic of high-quality development of the industrial chain is analyzed from three aspects: optimizing integration model, planting structure, and the quality of inputted factors.

Since the growth rate of industrial chain output is similar in structure and has stable mathematical characteristics, we explore the optimization strategies in different integration models based on the growth rate of production and factors inputted in various models. Formulas (5), (10) and (13) illustrated that the independent variables of the industrial chain output growth rate include sectors' output growth rate and the factors' (labor and technology) growth rate. On the one hand, the growth rate of sectors' output (Y_{Pr} , Y_{Mr}) depends on the difference of factors' marginal productivity (δ_{ij}), output elasticity (α_{ij}), and planting structure (θ); On the other hand, factors' input not only directly affects the output of the industrial chain, but also indirectly affects the growth rate of sectors' output. Therefore, the growth rate of sectors' output and input factors have an external economy and internal complementary, which determines the non-uniqueness of the high growth model.

In addition, the diversification of the members in the industrial chain and the diversification of decision-making will also present various forms of high growth patterns. In Formulas (5), (10) and (13), the output growth rate of the industrial chain is affected by the factors' growth rate and has a similar mechanism. To make the research more concentrated, we set the inputted factors and analyzed the marginal growth rate of sectors' output in different industrial models as follows:

The planting structure determines the integration model. Because the marginal growth rates of the three integration modes are linear, generally, parameters a , b , c and θ make the Model 3 have a high growth. In particular, when $\theta = 0$, Model 3 is the same as Model 1, and when $\theta = 1$, Model 3 is the same as Model 2; then, the output scale satisfy the conditions: $a_2 = c_3$ and $b_2 = c_2$. When $A \geq 0$, there is $B \leq 0$, and Model 2 is high growth model. On the contrary, when $A \leq 0$, there is $B \geq 0$, Model 1 is high growth model, where, $A = \theta \left(\frac{b_2 \alpha_{12}}{1 + \delta_{23}} - \alpha_{13} a_2 \right)$ and $B = (1 - \theta) \left(\alpha_{13} a_2 - \frac{b_2 \alpha_{12}}{1 + \delta_{23}} \right)$.

Numerical analysis

Based on the above mechanism analysis, we employ empirical data to estimate parameters and conduct numerical analysis for various strategy combinations across different models. This dual approach simulates industrial economic development by optimizing the industry structure and identifying the rationale behind relevant strategies and policy choices.

Parameters estimation. The data is derived from the panel data of 31 provinces in China from 2004 to 2020. The matching data was collected from the *China Statistical Yearbook*, *China Industrial Statistical Yearbook*, *China Science and Technology Statistical Yearbook*, and *China Education Statistical Yearbook* to estimate the parameters α_{12} , α_{13} , α_{23} , δ_{13} , δ_{23} and θ .

For the convenience of expression, we introduce the concept of industrial chain value-added, which is defined as the total output value of the industrial chain relative to a reference value. The

Table 2 Regression results of the original formulas.

Variable - Model and Regression Formula	Model 1 Formula (5)	Model 2 Formula (10)	Model 3 Formula (13)
The growth rate of agricultural output (Y_{Pr})	0.617 (8.56)***	0.214 (4.35)***	0.272 (4.00)***
The growth rate of manufacturing output (Y_{Mr})		0.483 (13.29)***	0.336 (8.67)***
The growth rate of human capital accumulation (L_{ir})	0.219 (4.40)***	0.050 (1.22)	0.222 (2.94)***
Growth rate of R&D investment (T_{ir})	0.014 (0.50)	0.048 (1.30)	0.042 (0.98)
Coefficients	0.025 (4.89)***	0.027 (6.62)***	0.031 (6.58)***
F-values	68.40	459.70	270.30
adj. R^2	0.328	0.764	0.670
n	527	527	527

The value of t is in brackets.

***p < 0.01.

output of the industrial chain is different in different models. According to the design of the regression models in Model 1, the production of the industrial chain includes agricultural products and direct consumption (according to the division of the wholesale and retail industry of the agricultural product market in the *China Statistical Yearbook*, including meat, poultry, eggs, aquatic products, vegetables, dried, fresh fruits, cotton, hemp, native animals, tobacco, flowers, birds, insects, fish, other products, accommodation and catering, etc.). In Model 2, the industrial chain output includes agricultural products, manufacturing, and consumption after manufacturing. In Model 3, the industrial chain output includes agricultural products, manufacturing, direct consumption, and post-manufacturing consumption.

Variables Y_{ir} , $i = 1, 2, 3$ are the growth rate of industrial chain output in model i . Growth rate formula is $Y_{ir} = (Y_n/Y_{2004})^{1/(n-2004)} - 1$, $n = 2005, \dots, 2020$, take 2004 as the base to calculate the growth rate of various variables from 2005 to 2020.

Variables Y_{Pr} and Y_{Mr} are the growth rates of agricultural and manufacturing sectors. According to the division of manufacturing sub-categories in the *China Industrial Statistical Yearbook*, manufacturing data come from agricultural and sideline food processing, food manufacturing, wine, beverage, tea manufacturing, tobacco products, textiles, clothing, clothing products, paper manufacturing, etc.

Variable L_{ir} is the growth rate of human capital accumulation in model i . Human capital accumulation is the product of the number of employees and the average number of years of education. Among them, the values of below primary school, primary school, middle school, high school (secondary vocational school), and above junior college are set with 0, 6, 9, 12 and 15, respectively.

Variable T_{ir} is the growth rate of R&D internal expenditure in model i . The regression results of the three models in formulas (5), (10) and (13) are relatively stable, as shown in Table 2.

Table 2 illustrates that all variables significantly positively impact the output of the industrial chain. It shows that the growth rate of agriculture, manufacturing, inputted labor, and technology significantly impact the industrial chain output growth rate.

To measure the internal factor productivity of a sector and the external effects between two sectors, we estimate the parameters δ_{ij} and α_{ij} . Theoretically, the internal factor productivity (δ_{ij}) and external effects (α_{ij}) in different models are different, and the parameters in different models cannot be estimated only based on the regression results in Table 2. Estimating parameters and comparing the consistency of the parameters estimated by different models is necessary. So, we expand Formulas (5), (10) and (13) and obtain the regression formula as shown in

Formulas(14) - (16).

$$Y_{1r} = \frac{\delta_{13}(a_1 Y_{Pr})}{1 + \delta_{13}} + \alpha_{13}(a_2 Y_{Pr}) + a_3 L_{1r} + a_4 T_{1r} \quad (14)$$

$$Y_{2r} = \frac{\delta_{13}(b_1 Y_{Pr})}{1 + \delta_{13}} + \frac{\alpha_{12}(b_2 Y_{Pr})}{1 + \delta_{23}} + \frac{\delta_{23}(b_2 Y_{Mr})}{1 + \delta_{23}} + \alpha_{23}(b_3 Y_{Mr}) + b_4 L_{2r} + b_5 T_{2r} \quad (15)$$

$$Y_{3r} = \frac{\delta_{13}c_1 Y_{Pr}}{1 + \delta_{13}} + \frac{\theta\alpha_{12}c_2 Y_{Pr}}{1 + \delta_{23}} + (1 - \theta)\alpha_{13}c_3 Y_{Pr} + \frac{\delta_{23}c_2 Y_{Mr}}{1 + \delta_{23}} + \alpha_{23}c_3 Y_{Mr} + c_4 L_{3r} + c_5 T_{3r} \quad (16)$$

Where, $Y_{1r} = dY_1/Y_1$, $Y_{2r} = dY_2/Y_2$ and $Y_{3r} = dY_3/Y_3$ are the output growth rate of the industrial chain. $Y_{Pr} = dY_P/Y_P$ and $Y_{Mr} = dY_M/Y_M$ are the output growth rate in sector P and M . $L_{1r} = dL_1/L_1$, $L_{2r} = dL_2/L_2$ and $L_{3r} = dL_3/L_3$ are the growth rate of labor inputted in the industrial chain. $T_{1r} = dT_1/T_1$, $T_{2r} = dT_2/T_2$ and $T_{3r} = dT_3/T_3$ are the growth rate of technology inputted in the industrial chain. $a_1 = Y_P/Y_1$, $b_1 = Y_P/Y_2$ and $c_1 = Y_P/Y_3$ are the output proportion in sector P . $b_2 = Y_M/Y_2$ and $c_2 = Y_M/Y_3$ are the output proportion in sector M . $a_2 = Y_C/Y_1$, $b_3 = Y_C/Y_2$ and $c_3 = Y_C/Y_3$ are the output proportion in sector C . $a_3 = h'_{LC}/(Y_1/L_1)$, $b_4 = h'_{LC}/(Y_2/L_2)$ and $c_4 = h'_{LC}/(Y_3/L_3)$ are the labor output elasticity in sector C . $a_4 = h'_{TC}/(Y_1/T_1)$, $b_5 = h'_{TC}/(Y_2/T_2)$ and $c_5 = h'_{TC}/(Y_3/T_3)$ are the technical output elasticity in sector C .

The results as shown in Table 3 can be obtained by sorting out the matching panel data to receive the variables in the above formulas.

The parameter equations and values shown in Table 4 are obtained by combining them with Tables 2 and 3.

According to the panel data, the output proportions of $a_1 = 0.84$, $a_2 = 0.16$, $b_1 = 0.50$, $b_2 = 0.47$, $b_3 = 0.07$, $c_1 = 0.43$, $c_2 = 0.40$ and $c_3 = 0.13$ are calculated. The difference in parameters between original formulas and expanded formulas can be found. Based on the regression parameters value of the expanded Formula (14)–(16), substituting them into the parameters equation of the original formulas, the results are estimated: $\frac{a_1\delta_{13}}{1+\delta_{13}} + a_2\alpha_{13} = 0.721$, $\frac{b_2\delta_{23}}{1+\delta_{23}} + b_3\alpha_{23} = 0.487$, $\frac{c_1\delta_{13}}{1+\delta_{13}} + \frac{c_2\theta\alpha_{12}}{1+\delta_{23}} + c_3(1 - \theta)\alpha_{13} = 0.333$, $\frac{c_2\delta_{23}}{1+\delta_{23}} + c_3\alpha_{23} = 0.410$, they are consistent with the regression results of the original Formula (5), (10) and (13). Therefore, the regression results of expanded formulas can be used to estimate the value of parameters δ_{ij} and α_{ij} , as shown in Table 5.

In Table 5, planting structure $\theta(0 < \theta < 1)$ is the proportion of agricultural output used for manufacturing. Similarly, $1 - \theta$ is the

Table 3 Regression results of expanded formulas.				
Variable - Model and Regression formula		Model 1 Formula (14)	Model 2 Formula (15)	Model 3 Formula (16)
Agricultural output proportion (a_1, b_1, c_1)	× Growth rate of agricultural	0.557(7.42)***	0.753(15.80)***	0.463(8.70)***
	(Y_{Pr})			
Manufacturing output proportion (b_2, c_2)			−0.151(−1.59)	0.842(6.39)***
Output proportion of service (a_2, c_3)		1.591(4.94)***		−1.563(−4.41)***
Manufacturing output proportion (b_2, c_2)	× Growth rate of manufacturing	0.124(2.06)**	0.848(15.39)***	0.449(8.14)***
	(Y_{Mr})			
Output proportion of service (b_3, c_3)			1.184(8.93)***	1.781(10.48)***
Growth rate of human capital accumulation (L_{ir})			−0.0589(−1.38)	−0.0681(−1.45)
Growth rate of R&D investment (T_{ir})		0.0203(0.66)	0.0642(2.32)**	0.0307(0.93)
Coefficients		0.0195(3.81)***	0.0152(4.41)***	0.0142(4.91)***
F-values		65.11	581.50	548.6
adj. R^2		0.360	0.833	0.850
n		527	527	527
The value of t is in brackets. ** $p < 0.05$, *** $p < 0.01$.				

Table 4 Comparison between original formulas and expanded formulas.			
Original formulas	Parameters equation (Value)	Expanded formulas	Parameters equation (Value)
Model 1 Formula (5)	$\frac{a_1\delta_{13}}{1+\delta_{13}} + a_2\alpha_{13} = 0.617$	Model 1 Formula (14)	$\frac{\delta_{13}}{1+\delta_{13}} = 0.557, \alpha_{13} = 1.591$
Model 2 Formula (10)	$\frac{b_1\delta_{13}}{1+\delta_{13}} + \frac{b_2\alpha_{12}}{1+\delta_{23}} = 0.214$	Model 2 Formula (15)	$\frac{\delta_{13}}{1+\delta_{13}} = 0.753$ $\frac{\delta_{23}}{1+\delta_{23}} = 0.848, \alpha_{23} = 1.184$
Model 3 Formula (13)	$\frac{c_1\delta_{13}}{1+\delta_{13}} + \frac{c_2\theta\alpha_{12}}{1+\delta_{23}} + c_3(1-\theta)\alpha_{13} = 0.272$ $\frac{c_2\delta_{23}}{1+\delta_{23}} + c_3\alpha_{23} = 0.336$	Model 3 Formula (16)	$\frac{\delta_{13}}{1+\delta_{13}} = 0.463, \frac{\theta\alpha_{12}}{1+\delta_{23}} = 0.842$ $(1-\theta)\alpha_{13} = -1.563, \frac{\delta_{23}}{1+\delta_{23}} = 0.449, \alpha_{23} = 1.781$

Table 5 Parameters estimation.			
Models/Parameters	Model 1	Model 2	Model 3
Difference in marginal productivity between two sectors (δ_{ij})	$\delta_{13} = 1.257$	$\delta_{13} = 1.700, \delta_{23} = 1.914$	$\delta_{13} = 1.045, \delta_{23} = 1.014$
External elasticity between two sectors (α_{ij})	$\alpha_{13} = 1.591$	$\alpha_{23} = 1.184$	$\alpha_{23} = 1.781, \alpha_{12} = 1.695/\theta$ $\alpha_{13} = -1.563/(1-\theta)$

proportion of agricultural output directly used for consumption. The estimated values of each parameter have little difference, and it can be considered that the estimates of the above parameters are stable in a large range. Where $\delta_{13}, \delta_{23} > 0$ (1.257, 1.700, 1.045, 1.914, 1.014) indicates that the marginal productivity of labor and technology in sector P and sector M is greater than that in sector C . $\delta_{12}, \delta_{23} > 0$ (1.685/ θ , 1.184, 1.781) suggests that sector P has a high output elasticity to sector M . Sector M has a high output elasticity to sector C . $\alpha_{13} > 0$ (1.591) in Model 1. In contrast, $\alpha_{13} < 0$ (−1.563/(1− θ)) in Model 3 shows that the output elasticity of sector P to sector C differs in different models. That is, the Model 3 is better than that of Model 1.

Since the marginal productivity of labor and technology in sector P is higher than that of the other two sectors, increasing factors input in sector P can increase sector M 's output, then improve sector C 's output. It can be attributed to increased R&D investment in sector P , improved agricultural operations scaling, and agricultural mechanization efficiency. We refer to input-output efficiency, which saves costs through technological investment and optimized labor allocation. According to the "Compilation of National Agricultural Cost Benefit Data"

(compiled by the National Bureau of Statistics in China), data from 2020 show that in food and economic crop production areas, cost reductions range from 20% to 40%. The essence of this phenomenon is the combination of technical, allocation, and dynamic efficiency. Technical efficiency refers to reducing unit output costs driven by mechanical precision work. Allocation efficiency refers to the optimization of resource allocation through the flow of labor across sectors. Dynamic efficiency refers to the investment in innovation that drives the sustained upgrading of agriculture. According to statistics from the Chinese Ministry of Agriculture and Rural Affairs, the contribution rate of agricultural scientific and technological progress was 60% in 2020, with mechanization contributing over 35%. It validates the synergy between productivity and efficiency.

Integration model affects industrial chain output. The output growth rate and the trend in the three models of the industrial chain output growth rate can be obtained as shown in Fig. 1. Consequently, we compare the models' impact on the output growth rate and summarize the high-growth patterns of different models.

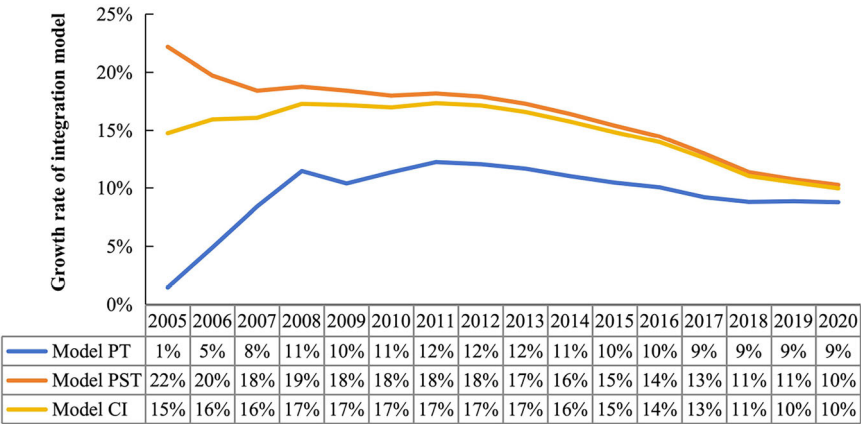


Fig. 1 Integration model and industrial chain output growth rate.

Table 6 Planting structure and industrial chain output growth rate.				
Planting structure	Changes in the industrial chain output growth rate (given Δθ)			
	Δθ = 0.1	Δθ = 0.2	Δθ = 0.3	Δθ = 0.4
θ = 0.2	ΔY _{3r} = 1.83%	ΔY _{3r} = 3.67%	ΔY _{3r} = 5.50%	ΔY _{3r} = 7.33%
θ = 0.4	ΔY _{3r} = 1.11%	ΔY _{3r} = 2.22%	ΔY _{3r} = 3.34%	ΔY _{3r} = 4.45%
θ = 0.6	ΔY _{3r} = 1.00%	ΔY _{3r} = 2.00%	ΔY _{3r} = 3.01%	-

The integration model nudges the transformation of industrial structure and high-quality development in the industrial economy. The integration model is one of the critical factors affecting the growth of industrial chain output. Figure 1 shows that all three models show a downward trend, a specific fact of industrial economic structure transformation and industrial economic development. Among them, Model 2 has the highest industrial chain output growth rate, followed by Model 3, with Model 1 being the lowest. Model 2 and 3 achieve higher industrial chain output growth rates than Model 1. This result arises from the transfer of rural labor to sector *M* and sector *C*, particularly the significant shift to sector *C*, and other factors such as the scientific and technological inputted to sector *M*, which are further reflected in the higher marginal productivity in sector *P* and sector *M*, as well as the higher output elasticity of the industrial chain. The result of these reasons is higher marginal productivity ($\delta_{13}, \delta_{23} > 0$) in sectors *P* and *M* and higher output elasticity ($\delta_{13}, \delta_{23} > 0$) on the industrial chain.

Planting structure affects industrial chain output. Theoretically, the difference between the structure of agricultural output used for manufacturing and directly used for consumption without manufacturing will inevitably lead to a difference in the value-added.⁴ According to the previous assumption design, when $\theta = 0$, it means that all agricultural output is inputted in sector *C*, when $\theta = 1$, it means that all agricultural production is inputted in sector *M*, when $0 < \theta < 1$, it means that one part of the agricultural output is inputted in sector *M*, and the other part is inputted in sector *C*. To optimize the planting structure, we take the representative integration model 3 as a specific example to discuss the impact of planting structure (θ) on the industrial

chain growth rate. Assuming that the planting structure increases from the original value θ to $\theta + \Delta\theta$, and $0 < \Delta\theta < 1$, the change of the industrial chain growth rate in Model 3 can be obtained from Formula (16), as $\Delta Y_{3r} = \left(\frac{\Delta\theta\alpha_{12}}{1+\delta_{23}}c_2 - \Delta\theta\alpha_{13}c_3 \right) Y_{Pr}$, since $\alpha_{13} < 0$, there is $\frac{\Delta\theta\alpha_{12}}{1+\delta_{23}}c_2 - \Delta\theta\alpha_{13}c_3 > 0$. When the planting structure is increased, the marginal contribution of sector *P* to the industrial chain output growth rate can be improved, and the output of the industrial chain can be accelerated. Changes in industrial chain output growth rate can be obtained, as shown in Table 6.

Table 6 illustrates that after every 0.1 unit increase based on θ , the output growth rate ΔY_{3r} will multiply, and the growth rate will vary in different current values. The growth rate ΔY_{3r} will be different based on different original θ values. It shows that optimizing the planting structure and increasing the proportion of agricultural products used for manufacturing can improve the industrial chain output growth rate. However, this growth model may be a law of marginal decline by optimizing the planting structure to guide industrial structure.⁵

This value creation process is shown as the interaction between the factor productivity within sectors and the output elasticity between two sectors. If we want to optimize the planting structure by increasing the manufacturing proportion, it is critical to deepen the manufacturing. Let more primary agricultural products be put into manufacturing, and use the sector's higher marginal productivity and output elasticity to give more added value to the industrial chain. Continuing to promote the transformation and development of industrial structure provide high-quality and diversified products. Upgrading the traditional "Secondary industry" into a functional industry integrate the independent experience and crowd-creation, effectively linking the "Primary industry" and "Tertiary industry", and realize the efficient and organic integration of the primary-secondary-tertiary industry.

Factor productivity affects industrial chain output. We separately discussed the marginal productivity of factors in sector *P* and sector *M*, as well as sector *M* and sector *C*, to compare the impact of changes in factor marginal productivity on the industrial chain output growth rate.

- (1) Increasing the difference in marginal productivity between sector *P* and sector *C* (δ_{13}) will increase the growth rate of industrial chain output. According to the estimation of parameters, if the productive agricultural proportion is $\theta = 0.4$, then $\delta_{13} = -3.776$; If $\theta = 0.5$, then $\delta_{13} = -2.514$; If $\theta =$

Table 7 Factors marginal productivity, and industrial chain output growth rate.

Changes of the industrial chain output growth rate ΔY_{3r} and the difference of factor marginal productivity $\Delta\delta_{13}$	Difference of factor's marginal productivity between sector <i>P</i> and sector <i>C</i> (δ_{13})		
	$\Delta\delta_{13} = 10\%$ $\Delta Y_{3r} = 0.10\%$	$\Delta\delta_{13} = 20\%$ $\Delta Y_{3r} = 0.19\%$	$\Delta\delta_{13} = 40\%$ $\Delta Y_{3r} = 0.36\%$
Changes of the industrial chain output growth rate ΔY_{3r} and the difference of factor marginal productivity $\Delta\delta_{23}$	Difference of factor's marginal productivity between sector <i>M</i> and sector <i>C</i> ($\Delta\delta_{23}$)		
	$\Delta\delta_{23} = 10\%$ $\Delta Y_{3r} = 0.20\%$	$\Delta\delta_{23} = 20\%$ $\Delta Y_{3r} = 0.38\%$	$\Delta\delta_{23} = 40\%$ $\Delta Y_{3r} = 0.69\%$

Table 8 Regression results of regional heterogeneity.

Variable—region	Eastern region	Central region	Western region
Agricultural output proportion (c_1) × Growth rate of agricultural (Y_{pr})	0.632(9.07)***	0.600(3.65)***	0.324(4.03)***
Manufacturing output proportion (c_2) × Growth rate of manufacturing (Y_{mr})	0.442(2.00)**	1.008(3.03)***	1.226(4.96)***
Output proportion of service (c_3)	−0.759(−1.68)*	−4.865(−3.92)***	0.093(0.10)
Manufacturing output proportion (c_2) × Growth rate of manufacturing (Y_{mr})	0.439(3.72)***	0.197(1.56)	0.370(2.83)**
Output proportion of service (c_3)	1.628(8.22)***	2.192(3.46)***	0.955(2.28)**
The growth rate of human capital accumulation (L_{3r})	−0.038(−0.53)	0.195(1.62)	0.018(0.21)
Growth rate of R&D investment (T_{3r})	0.074(2.95)	0.145(5.14)***	−0.016(−0.44)
Coefficients	0.011(3.22)***	0.009(2.38)**	0.018(2.92)***
F-values	286.52	397.24	121.21
adj. R^2	0.907	0.913	0.814
n	204	153	170

The value of *t* is in brackets.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

0.6, then $\delta_{13} = -1.885$. After increasing by 10%, 20% and 40%, respectively, based on the above values δ_{13} , the marginal contribution of the agricultural output growth rate to the industrial chain output growth rate (Y_{pr} in Formula (13)) increased, as shown in Table 7.

- (2) Increasing the marginal productivity difference between sector *M* and sector *C* (δ_{23}) will increase the industrial chain output growth rate. After rising by 10%, 20% and 40% based on the original estimation δ_{23} , the marginal contribution of sector *M* and sector *C*'s output growth rate to the industrial chain output growth rate (Y_{pr} and Y_{mr} in Formula (13)) will increase too, as shown in Table 7.

Table 7 illustrates that increasing the difference of factors' marginal productivity between sectors *P* and *C* (improving the marginal productivity of the factors in sector *P*, given the marginal productivity of the factors in sector *C*) can improve the industrial chain output growth rate. Similarly, increasing the difference of factors marginal productivity between sector *M* and sector *C* (improving the marginal factor productivity of sector *M*, given the factor marginal productivity of sector *C*) can improve the output growth rate of the industrial chain. Therefore, comprehensive improvement of inputted factors can supplement the vitality of industrial economic growth. Improving the quality of inputted factors can enhance the productivity of labor and technology, such as improving the quality of human capital, enhancing technology investment, and promoting technological innovation.

Regional heterogeneity analysis. We compare the differences in the value-added of industrial chains and their influencing factors

in different regions to propose more targeted suggestions based on the characteristics and advantages of each region. We choose the commonly used method of dividing three regions to divide into the eastern region⁶, the central region⁷, and the western region⁸. By performing regression analysis on Formula (16) in model 3, the results shown in Table 8 can be obtained.

According to Table 8, the parameter equations and values shown in Table 9 can be obtained.

A comparison of the three regions' marginal productivity and the external elasticity can be obtained by comparing the regression results of Mode 3 in Table 9 with those in Table 5, as shown in Table 10.

According to Table 10, there is consistency in labor and technical productivity among the three regions. δ_{13} is the marginal productivity of the agricultural sector and consumer service sector. δ_{23} is the marginal productivity of the manufacturing sector and consumer service sector. The numerical values of δ_{13} exhibit a hierarchical pattern: the eastern region ranks highest, followed by the central region, with the western region being the lowest. It indicates that the marginal productivity of labor and technology in the agricultural and manufacturing sectors exceeds that of the consumer service sector. Moreover, the marginal productivity displays regional differentiation. δ_{23} has similar performance to δ_{13} , except that it is not significant in the central region. Compared with the national average level ($\delta_{13} = 1.045$, $\delta_{23} = 1.014$), the agricultural productivity in eastern and central regions is higher than the national average. In comparison, the agricultural productivity in the western region is lower than the national average level. Meanwhile, the agricultural manufacturing productivity in the

Table 9 Comparison of parameters in heterogeneity regression.

Eastern region		Central region		Western region	
Formula	Value	Formula	Value	Formula	Value
$\frac{\delta_{13}}{1+\delta_{13}} = 0.632$	$\delta_{13} = 1.717$	$\frac{\delta_{13}}{1+\delta_{13}} = 0.600$	$\delta_{13} = 1.500$	$\frac{\delta_{13}}{1+\delta_{13}} = 0.324$	$\delta_{13} = 0.479$
$\frac{\theta\alpha_{12}}{1+\delta_{23}} = 0.442$	$\alpha_{12} = 0.788/\theta$	$\frac{\theta\alpha_{12}}{1+\delta_{23}} = 1.008$	—	$\frac{\theta\alpha_{12}}{1+\delta_{23}} = 1.226$	$\alpha_{12} = 1.946/\theta$
$(1-\theta)\alpha_{13} = -0.759$		$(1-\theta)\alpha_{13} = -4.865$		—	
$\frac{\delta_{23}}{1+\delta_{23}} = 0.439$	$\delta_{23} = 0.783$	—		$\frac{\delta_{23}}{1+\delta_{23}} = 0.370$	$\delta_{23} = 0.587$
$\alpha_{23} = 1.682$		$\alpha_{23} = 2.192$		$\alpha_{23} = 0.955$	

Table 10 Comparison of sectors' development in three regions.

		Eastern region	Central region	Western region
Difference of factor's marginal productivity	Agricultural and manufacturing sector	High	High	Low
	Manufacturing and service sector	Low	—	Low
External elasticity between sectors	Agricultural and manufacturing sector	Low	—	High
	manufacturing and service sector	Low	High	Low

eastern and western regions is lower than the national average. It indicates that the agricultural R&D investment, labor skills, and efficiency of agricultural mechanization in western region need to be improved, and the productivity of agricultural product processing has not achieved a breakthrough. The agricultural production in the eastern region has been developed, but the manufacturing of agricultural products has not been completed locally.

The external elasticity between two sectors has the following characteristics: $\alpha_{12}, \alpha_{23} > 0$ it indicates that the agricultural sector has a high output elasticity towards the manufacturing sector. In contrast, the manufacturing sector has a high output elasticity relative to the service sector. Compared with the national average level ($\alpha_{12} = 1.695/\theta$, $\alpha_{23} = 1.781$), given θ , the external impact of agricultural production on manufacturing in the western region is higher than the average level, while the external effect of agricultural production on manufacturing in the eastern region is lower than the average level. The central region experiences the highest external impact of manufacturing on consumption, followed by the eastern region, with the western region having the lowest. Agricultural products from the western region significantly boost the manufacturing output value in the central and eastern regions. Meanwhile, the manufacturing output in these regions, particularly in the central region, also increases local consumption output value. Regional disparities and imbalances exist in agricultural production, manufacturing and consumption.

This regional development imbalance originates from a dual pressure mechanism: the eastern region faces eroding traditional competitiveness due to rising factor costs, whereas the western region is trapped in a persistent 'resource endowment lock-in' dilemma. Such spatial economic differentiation epitomizes the coexistence of structural contradictions inherent in China's economic transition and persistent inter-regional developmental asymmetries, reflecting the complex dynamics of spatial resource allocation during industrial upgrading processes. Achieving breakthroughs in structural contradictions and restructuring spatial economic efficiency is imperative.

International experience

The development of industry economics needs to rely on the high-added-value of the industry chain and the productivity

improvement of agricultural production and manufacturing. Therefore, it is of great significance to explore the general rules of industry structure adjustment, analyze the differences in industry structure between developed and emerging economies, and reveal the laws of industry structure, agricultural industrial chain, and industrial economic development of developed economies that have achieved high-quality economic growth, as well as emerging economies in transition.

Considering the total GDP (Gross Domestic Product) and population in 2016, data from 32 non-oil export-oriented economies from 1980 to 2016 were selected. It includes 21 developed economies⁹ and 11 emerging economies¹⁰. The *per capita GDP* (current price/USD) data comes from the World Macroeconomic Database, agricultural added value, agricultural products, and manufacturing data¹¹ from the World Agroforestry Database. The scale of these data is shown in Fig. 2.

Figure 2 shows that the *per capita GDP* of the two economies has fluctuated over time. Still, the gap between them is significantly widening, which will continue for a long time. Developed economies' *per capita GDP* and agricultural products have almost maintained the same changes. After 2002, agricultural products and manufacturing in developed economies showed a slight rise trend, while their *per capita GDP* showed a significant growth. It indicates that factors other than agriculture mainly cause the economic growth of developed economies. However, emerging economies have demonstrated unprecedented and coordinated growth in *per capita GDP*, agricultural products, and manufacturing, with their trends aligning closely. Therefore, the rapid development of agriculture and manufacturing industries in emerging economies is one of the essential driving forces for their rapid economic growth. The matching of *per capita GDP* with agricultural data provides a significant reference value for illustrating the development patterns of developed and emerging economies using various indicators.

To verify the relationship between the level of economic development and the quality of agricultural development, we analyze the relationship between the agricultural added value and the *per capita GDP* growth data of the two economies¹², as shown in Fig. 3. From the relationship between *per capita GDP* and agricultural added value, the developed economies have slow growth relations with *per capita GDP*, and the emerging economies show rapid growth relations with *per capita GDP*¹³. For developed economies, it is relatively easy to increase their *per*

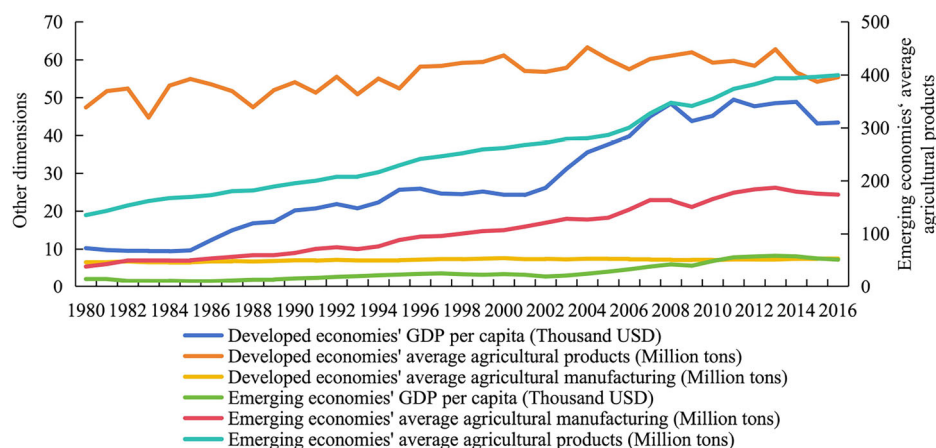


Fig. 2 Scale of per capita GDP, agricultural products, and manufacturing.

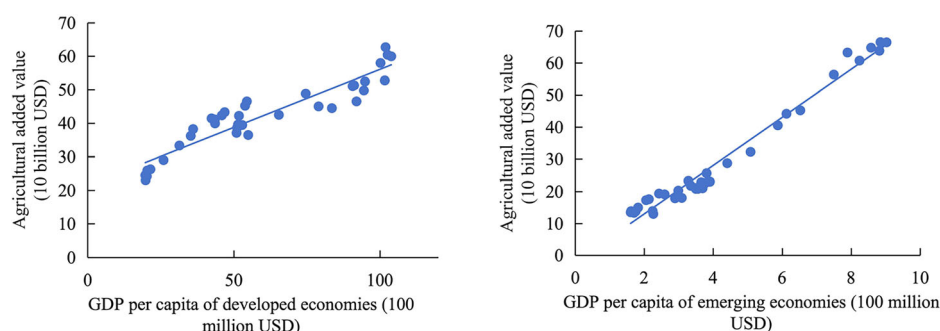


Fig. 3 Relationship between per capita GDP and agricultural added value.

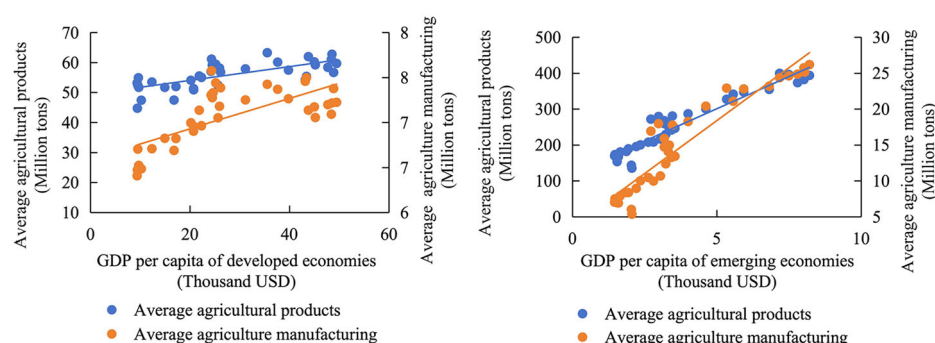


Fig. 4 Relationship between agricultural products, manufacturing, and per capita GDP.

capita GDP by increasing agricultural added value; For emerging economies, it is relatively complex to increase their *per capita GDP* by increasing agricultural added value, and the rising path is not sustainable.¹⁴ Therefore, optimizing the structure of the three major industries to promote economic development is necessary for emerging economies, among them optimizing the industry structure, improving the added value of manufacturing, and promoting the transfer of the economic development dominated by the primary sector to the secondary and tertiary sectors.

The agricultural products and manufacturing indicators of the two different economies were investigated to reveal further the role of planting structure on economic growth, as shown in Fig. 4. It is found that the *per capita GDP* of the two economies and these two indicators (agricultural products and manufacturing)

have the same relationships. Compared with agricultural products, manufacturing has a higher marginal contribution to *per capita GDP*, and emerging economies have a higher marginal contribution to *per capita GDP* than developed economies. Among them, the *per capita GDP* of developed economies and the proportion of manufacturing (0.13) are relatively high, and the part of agriculture produced for manufacturing, as the intermediate input of manufacturing, has a more vital role in promoting the increase of the added value of the industrial chain. However, the *per capita GDP* and manufacturing share in emerging economies are lower (0.06). The value-added industry chain depends on traditional material capital investment but will fall into the “Kaldor fact”. The development of productive agricultural proportion depends on upgrading the industrial chain

and the development level of agricultural manufacturing, which has a negligible effect in promoting the value-added of industry chain. The *per capita GDP* of developed economies is matched with the high added value created by the high proportion of manufacturing. In contrast, the *per capita GDP* of emerging economies is compared with the agricultural added value and the high annual growth rate of the manufacturing proportion.

Therefore, developed and emerging economies are at different stages of development in “promoting industrial economic growth through manufacturing”. It undoubtedly confirms the scholars’ division of the driving forces for the transformation of different economies: the transformation of developed economies is more like a process of natural evolution driven by capital accumulation and technological change. The transformation of emerging economies is driven by the “structural dividend” under the external effects. Therefore, for emerging economies, the development path of realizing the overall industrial economic transformation through the “external role” of agricultural structural transformation is worth emulating.

Conclusions and discussion

Conclusions. Through studying the relationship between the transformation of industrial structure and industrial economic growth, it is found that the integration model, planting structure, and the quality of inputted factors explain the essential role of the transformation of industrial structure and affect the development speed of industrial economy. From practical experience, there is a strong dependence relationship between the added value of industrial chain and integration model, planting structure, manufacturing development, human capital accumulation, and technological innovation. Agriculture, manufacturing, and service industries have inseparable internal relations and external effects on industrial economic growth.

Several conclusions are summarized from the perspective of industrial chain: ①Agricultural industry has a significant spillover effect on manufacturing industry, and manufacturing industry has a significant spillover effect on service industry. ②The marginal productivity of factors in agriculture and manufacturing is higher than in the service industry. ③Integration model, planting structure, and input factor quality have significant external effects on the value-added of industrial chain. ④There are structural contradictions and regional imbalances in agricultural industry. The research shows that relying on the development of manufacturing, optimizing the planting structure, and improving the quality of input factors can promote the development of agricultural industry. Increasing the proportion of manufacturing can encourage the transformation of industrial structure, and the high-quality development of the industrial economy.

From the perspective of international experience, the correlation between *per capita GDP* and manufacturing proportion is higher in developed economies than in emerging economies. The proportion of agriculture produced for manufacturing plays a more vital role in increasing the added value of industrial chain. The *per capita GDP* and the manufacturing proportion of emerging economies are relatively lower than that of developed economies, which plays a less essential role in promoting the value-added of agricultural industry. It shows that the two different economies are at various stages of development in “promoting industrial economic growth through agricultural and manufacturing industry”. In addition, the annual growth rate of agriculture and manufacturing in emerging economies is significant. In particular, the proportion of manufacturing is relatively similar with China¹⁵. Emerging economies’ agricultural-based industrial structure and economic development mode are gradually transforming. For emerging economies, optimizing and

upgrading manufacturing under the “external role” can narrow the per capita GDP gap between emerging and developed economies and promote the smooth transition from the “slow-down” stage to the rapid growth stage of industrial economy.

Limitations and future research directions. Further research and expansion are still necessary in the future. Although we have felt the “pulse” of industrial integration, it is a systematic project, and the imbalance between regions affects the measurement of industrial integration and its impact effect. In the relatively developed eastern region, the proportion of manufacturing is significant, while the annual growth rate is lower than others. In the central and western regions with relatively backward economies, the proportion of manufacturing is smaller, but the yearly growth rate is higher. The development gap between these regions will gradually flatten through industrial structure optimization. This optimization is essential for high-quality industrial economic development and ultimately determines the quality of agricultural economic growth. Therefore, implementing the agricultural revitalization strategy is necessary for building a modern industry economic system. It is critical to expand research on international comparisons of the coordinated development of agriculture and manufacturing, such as from political and social dimensions. It is essential to conduct in-depth heterogeneity research on 32 non-oil export-oriented economies. Covering the differentiated paths of developed and emerging economies, revealing the profound impact of institutional environment differences on the integration of industry chain.

Recommendations. Many national policies and technologies in China have driven the growth of agriculture and manufacturing industries. The “*National Innovation-driven Development Strategy Outline*”, “*Rural Revitalization Strategic Plan (2018–2022)*” and “*China Central Document*” mentioned a series of policies, including subsidies and price support, industrial upgrading strategy, and rural digitalization strategy. Technological innovations include precision agriculture, digitalization of agricultural platforms, and biotechnology.

It is beneficial to continue promoting the transformation of industry structure by optimizing planting structure, increasing the proportion of manufacturing, innovating manufacturing technology, and improving the quality of input factors. It is necessary to upgrade the traditional secondary industry into a functional industry that integrates the independent experience and self-creation, effectively links the primary industry and tertiary industry, and realizes the organic integration of the primary-secondary-tertiary industry. We propose several policy suggestions for transforming the industry structure.

①In terms of production, establishing specialized crop production areas and implementing multiple crop rotation patterns will optimize the planting structure. Implementing the agricultural land cooperative system and innovative agriculture model will improve agriculture’s production proportion and efficiency. Order-agriculture and establishing a fully managed social service system will promote the organic connection between small farmers and modern agriculture. Establishing processing industry clusters and launching the “Industrial Raw Material Crop Seed Cultivation” program will increase the proportion of agricultural production used for manufacturing. Establishing a standard system for the entire industry chain, implementing specialized division of labor, and brand building will improve the standardization and specialization of agricultural production.

②Regarding manufacturing, we should develop diversified agricultural manufacturing industries and improve the value-

added efficiency of all-round agricultural transformation. For example, extending the industrial chain through functional food development, bio-based material manufacturing, and other means and combining modern production technology to achieve horizontal cross-border integration and innovation. Innovate production technology through digital manufacturing technology and biotechnology empowerment. Expand agriculture's multi-functional integrated development mode through agricultural industrial tourism complexes and circular economy closed-loop design.

③In terms of quality of input factors, the level of education and agricultural mechanization in the agricultural sector should be improved, thereby improving the efficiency of agricultural operations and providing basic supplies for manufacturing. In the manufacturing sector, it is necessary to enhance the technological level and deep manufacturing capabilities to add value of industrial chain. In the service sector, we should improve our promotional and marketing capabilities, innovate service modes, enhance service levels, and endow more innovative capabilities for the value creation.

④From the industrial chain, establish farmer shareholding cooperatives to coordinate the interest relationship between agricultural production and manufacturing. Improve the long-term cooperation mechanism between the primary and secondary industry operators by adopting methods such as order agriculture to lock in long-term production capacity. Establish collective trademarks for geographical indications and strengthen control over the industry value chain. Letting the added value of the industrial chain remain in the countryside, and farmers truly enjoy the wealth brought by the land, is the original intention of realizing the integration of primary-secondary-tertiary industry.

⑤This structural transformation necessitates creating a dual-circulation innovation corridor to bridge eastern and western developmental gap. Through deploying smart manufacturing clusters (such as AI-powered quality traceability systems) to synergistically propel the upgrading of agricultural processing ecosystems in western regions, coupled with establishing big-data-driven factor mobility platforms that accelerate cross-regional circulation, recombination, and sharing of advanced technology and capital (such as digital twin-integrated equipment sharing networks), the initiative ultimately constructs spatially embedded agricultural industrial value chains that optimize inter-regional productivity complementarity effects.

Data availability

The datasets generated and analyzed during the current study are available in the figshare repository.

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Notes

- 1 The "Dual-structure" of urban and rural areas in China refers to a structural state where there are significant differences and relative divisions between cities and rural areas in terms of economy, society, and other aspects.
- 2 The "structural dividend" hypothesis is an important theory in development economics, which holds that economic structural transformation (such as the transfer of labor, capital, and other factors from low productivity sectors to high productivity sectors) can significantly improve the overall productivity of society, thereby promoting economic growth. The logic behind it is generally driven by favorable policies, which promote the flow of high-quality factors and create more opportunities and possibilities for the development of this field than before.
- 3 Six Industries are primary industry + secondary industry + tertiary industry, and primary industry \times secondary industry \times tertiary industry.
- 4 Practically, some regions have a large output of agricultural products, but less manufacturing and consumption, while others have the opposite situation. It shows

that the spatial mobility of primary agricultural products is large, and the development between regions is uneven. Some regions have the production natural endowment of primary agricultural products, while others have the natural endowment of high consumption demand. The difference between regions that mainly produce primary agricultural products and regions that mainly process and consume agricultural products will become larger, which may aggravate the regional development disharmony.

- 5 This method of analysis is relatively conservative. Theoretically, the adjustment of agricultural planting structure will inevitably lead to the increase in the proportion of manufacturing output c_2 , the proportion of consumption service output c_3 , and the external elasticity α_{12} . At the same time, it will also lead to a decline of α_{13} , and a reduction difference in marginal productivity of labor and technology between sectors. Therefore, optimizing the agricultural planting structure can increase the output growth rate of the industrial chain more.
- 6 Including 12 provinces (cities and autonomous regions) of Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, and Hainan.
- 7 Including 9 provinces (regions) of Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan.
- 8 Including 10 provinces (cities and autonomous regions) of Chongqing, Sichuan, Guizhou, Yunnan, Xizang, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.
- 9 Including Japan, South Korea, Belgium, Denmark, the United Kingdom, Germany, France, Ireland, Italy, the Netherlands, Greece, Portugal, Spain, Austria, Finland, Norway, Switzerland, Canada, the United States, Australia, and New Zealand.
- 10 Including China, Brazil, India, South Africa, Malaysia, Thailand, Egypt, Kenya, Mexico, Argentina and Chile.
- 11 Due to the lack of data on the yield and manufacturing capacity of forest, animal husbandry and fishery, only the relevant data of crops are reviewed here. Among them, crop production includes grains, fruits, vegetables, beans, fiber, oil crops, tubers, tree nuts, feed and sugar crops; crop processing and manufacturing includes barley beer, sugar, soybean oil, peanut oil, coconut oil, palm oil, virgin olive oil, sunflower oil, rapeseed oil, red flower oil, sesame oil, corn oil, cottonseed oil, flaxseed oil, vegetable fat, catalpa oil, wine and short margarine, etc.
- 12 Firstly, we take the logarithm of the two groups data of developed and emerging economies' per capita GDP and agricultural added value respectively; then, get the linear regression results, $\ln add1 = 0.47 \ln GDP1 + 5.08$, $\ln add2 = 0.96 \ln GDP2 + 2.24$, $\ln GDP1 = 1.93 \ln add1 - 8.96$ and $\ln GDP2 = 0.98 \ln add2 - 1.78$. Where $add1$ is the agricultural added value of developed economies, $add2$ is the agricultural added value of emerging economies, $GDP1$ is the per capita GDP of developed economies, $GDP2$ is the per capita GDP of emerging economies. Finally, get a scatter plot and fitting curve of the two groups of data, as shown in Fig. 3, and the results are significant.
- 13 The data processing results show that the agricultural added value of developed economies increases by 0.47 times with each unit of per capita GDP, while that of emerging economies increases by 0.96 times with each unit of per capita GDP. On the contrary, from the perspective of the impact of agricultural added value on per capita GDP, the developed economies increased by 1.93 times with each unit of per capita GDP, while that of emerging economies for each unit of added value, the per capita GDP increases by 0.98 times.
- 14 From the experience of developed economies, the three major industrial structure changes are usually from the primary industry to the secondary and tertiary industries. Therefore, the effect of achieving economic growth by simply developing agricultural production is limited.
- 15 The corresponding Chinese data of this indicator is based on the output value (100 million yuan), while that of emerging economies is based on the processing volume (100 million tons), which cannot be directly compared. Between 2003 and 2017, China's agricultural output value increased by 2.68 times, and the output value of manufacturing increased by 8.28 times, which is an essential representative in emerging economies.

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Author contributions

Yufeng Hu: Funding acquisition, methodology, data curation, formal analysis, and writing- original draft. Zenglai Li: Conceptualization, formal analysis, editing, and supervision. Youqiang Ding: Data curation, Formal analysis, validation, writing-review, and editing.

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The authors declare no competing interests.

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