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The Impact of Rural Demographic Structure on Agricultural New-Quality Productivity in China: Evidence from a Panel Dataset of 30 Provinces

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Abstract

As China advances its rural revitalization and agricultural modernization, agricultural new-quality productivity (ANQP)—driven by technological innovation and efficient factor allocation—has become essential for achieving sustainable agricultural growth. This study examines how the rural demographic structure influences ANQP, focusing on four key dimensions: age, gender, household, and consumption. Using balanced panel data from 30 Chinese provinces spanning 2013–2022, a comprehensive ANQP index is constructed through the entropy-weight method, and a two-way fixed-effects model is employed, supplemented by robustness and heterogeneity tests. The results show that ANQP has steadily increased nationwide but remains significantly shaped by demographic characteristics. Specifically, population aging exerts a strong inhibitory effect by crowding out productive investment and slowing technology adoption, while gender imbalance weakens labor division efficiency and distorts resource allocation. In contrast, consumption upgrading acts as a positive driver by stimulating demand for high-quality agricultural products, whereas household size has no statistically significant effect. Regional heterogeneity further reveals diverse patterns—such as stronger aging constraints in central regions and pronounced positive effects of consumption upgrading in southern coastal areas. Overall, the findings underscore the critical role of demographic dynamics in driving agricultural transformation and provide evidence-based policy implications for promoting sustainable and innovation-led agricultural development.

Keywords: rural demographic structure; agricultural new-quality productivity; technological innovation; China's agricultural modernization

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1. Introduction

As global agriculture continues to modernize, China's rural revitalization strategy has made the cultivation of agricultural new-quality productivity (ANQP) a central driver of its transformation from a major agricultural country to an agricultural power [1]. As a management concept originally proposed in China, agricultural new-quality productivity (ANQP) is primarily rooted in Chinese academic and policy discourse; however, it aligns conceptually with international perspectives on innovation-driven, quality-oriented, and sustainable agricultural development. Unlike traditional productivity, agricultural new-quality productivity centers on scientific and technological innovation [2]. It enhances agricultural efficiency, quality, and sustainability through the reconfiguration of production

factors and the integration of new technologies, industries, and organizational models [3]. Empirical research further demonstrates that ANQP promotes green agricultural efficiency by advancing technological progress and optimizing resource allocation [4]. According to General Secretary Xi Jinping, the innovative allocation of production factors is essential to fostering new-quality productivity [5]. Among these factors, labor plays a pivotal role, and its structure decisively influences the trajectory of new-quality agricultural growth.

The evolution of the rural demographic structure is closely linked to the development of agricultural new-quality productivity [6,7]. On the one hand, demographic imbalances—such as labor outmigration and population aging—may hinder the spread of advanced agricultural technologies, limit emerging industries due to labor shortages, and slow innovation in production models, thereby restraining the growth of agricultural new-quality productivity [8]. On the other hand, rational demographic adjustments—such as attracting skilled young talent to rural areas and optimizing labor allocation—can boost agricultural new-quality productivity, promote the application of scientific and technological achievements, support new agricultural enterprises, and advance industrial integration [9,10].

Against this backdrop, it is of substantial theoretical and practical significance to conduct an in-depth investigation into the impact of rural demographic structure on agricultural new-quality productivity. From a theoretical perspective, such an inquiry contributes to enriching the body of research on the relationship between demographic structure and productivity in the field of agricultural economics, offering new insights into the underlying mechanisms of agricultural development. From a practical standpoint, it provides a solid foundation for the government to formulate sound and effective agricultural policies, rural revitalization strategies, and talent attraction and cultivation programs, thereby helping address pressing challenges in rural development, advancing the high-quality development of agriculture in China.

Building on the above considerations, this study systematically examines how the rural demographic structure influences agricultural new-quality productivity (ANQP), identifying its underlying patterns and mechanisms and offering insights with clear policy relevance.

The primary objective of this study is to examine how the rural demographic structure influences agricultural new-quality productivity (ANQP) in China. To address this objective, three specific questions are posed: (1) How do distinct demographic dimensions—age, gender, household, and consumption—affect the development of ANQP? (2) Do these effects operate in positive or negative directions, and how can such dual influences be theoretically interpreted? (3) To what extent do these relationships differ across regions with varying socioeconomic contexts? To address these research questions, this study integrates theoretical analysis with empirical testing to reveal the mechanisms and regional differences underlying the relationship between rural demographic structure and agricultural new-quality productivity. These questions form the foundation for the theoretical framework, empirical model, and regional analysis presented in the following sections.

This study makes several contributions to the existing literature. First, unlike previous research that has primarily explored rural population structure in relation to agricultural labor supply or traditional productivity, this paper centers on agricultural new-quality productivity—a concept emphasizing innovation, sustainability, and quality-driven growth. Second, it advances empirical understanding by systematically incorporating four demographic dimensions—age, gender, household, and consumption—into the analytical framework, thereby offering a more comprehensive perspective than prior single-dimensional approaches. Third, it enriches theoretical discourse by proposing and testing a set of competing hypotheses (H1a–H5b) that consider both potential positive and negative effects of demographic factors, moving beyond the one-sided assumptions prevalent in earlier studies. Finally, by performing a heterogeneity analysis across eight comprehensive economic zones,

the study reveals diverse regional patterns and derives more nuanced policy implications, particularly for designing region-specific strategies that support rural revitalization.

As shown in Figure 1, this study proceeds in a logical sequence from theoretical conception to empirical validation. The Introduction outlines the research background, significance, and objectives. Section 2 develops the theoretical framework and formulates research hypotheses grounded in existing literature. Section 3 describes the data sources, defines the variables, and specifies the econometric models. Section 4 presents and interprets the empirical results, linking them to theoretical insights and policy implications. Section 5 concludes the paper by summarizing the main findings and proposing practical recommendations for agricultural development, while Section 6 discusses the study's limitations and future research directions.

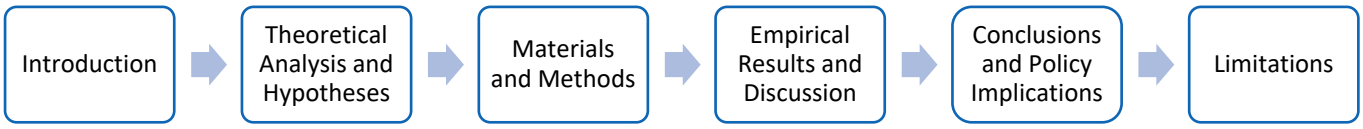


Figure 1. The overall structure of the study.

2. Theoretical Analysis and Research Hypotheses

Agricultural new-quality productivity (ANQP) is influenced by demographic as well as technological and institutional factors. To clarify these effects, we propose a set of hypotheses concerning the roles of age, gender, household, and consumption structures (H1a–H5b).

2.1. Age Structure of the Rural Population

The age structure of the rural population is divided into two components: the child dependency ratio and the elderly dependency ratio. The distribution of dependent and working-age populations has long-term and short-term implications for agricultural productivity. A higher child dependency ratio may signal potential for human capital accumulation, as educational investments in children can nurture future agricultural innovators and entrepreneurs. In contrast, a large child population increases household dependency burdens, limits disposable resources for productive investment, and constrains the current labor supply [11].

H1a: *A higher rural child dependency ratio enhances ANQP by fostering long-term human capital accumulation.*

H1b: *A higher rural child dependency ratio constrains AN QP in the short term by diverting productive investment and limiting labor availability.*

The elderly dependency ratio reflects the proportion of the rural population aged 65 and above. An increase in this ratio indicates a rising share of elderly laborers, whose learning ability and physical strength are limited. They tend to rely on traditional farming and adopt new technologies—such as intelligent machinery and digital monitoring—more slowly, hindering the promotion of precision agriculture and smart irrigation. However, their accumulated experience in climate patterns and crop cultivation can serve as an "invisible bridge" between traditional and modern technologies, helping optimize parameters for intelligent planting models [12].

H2a: *A higher rural elderly dependency ratio enhances ANQP by fostering long-term human capital accumulation.*

H2b: *A higher rural elderly dependency ratio constrains ANQP in the short term by diverting productive investment and limiting labor availability.*

2.2. Gender Structure of the Rural Population

An imbalanced rural gender ratio can significantly affect agricultural new-quality productivity. When the male proportion is excessively high, a traditional "male-dominated, labor-intensive, and technology-oriented" model tends to prevail. Under this structure, women have fewer opportunities for technical training or participation in tasks such as operating intelligent equipment and managing digital platforms, thereby limiting the full application of agricultural technologies [13].

Conversely, when the female proportion increases, women's strengths in meticulous management align with high value-added agricultural activities (e.g., organic fruits and vegetables). However, physiological and skill-related constraints in operating heavy machinery and undertaking complex technical decisions may create bottlenecks in technology adoption [14].

H3a: *A higher female proportion enhances ANQP by improving precision management, quality control, and agricultural e-commerce.*

H3b: *A more imbalanced gender ratio (male dominance) reduces ANQP by weakening labor division efficiency and diverting household resources away from productive uses.*

2.3. Household Structure of the Rural Population

The average rural household size has been shrinking, with nuclear families becoming dominant. Small-scale operations increase the marginal costs of technologies such as intelligent greenhouses and large-scale machinery, making it difficult for households to bear high investments and restraining the adoption of large-scale technologies [15]. Nevertheless, shrinking household size has stimulated the growth of land trusteeship services and cooperatives, which, through a "scattered households + centralized services" model, extend intelligent plant protection and IoT monitoring systems to smallholders. This, to some extent, mitigates the high marginal costs faced by small rural households [16,17].

H4a: *Larger rural households enhance ANQP by increasing labor supply and sustaining investment capacity.*

H4b: *Smaller rural households constrain ANQP by limiting scale economies, although agricultural socialized services may partially offset this effect.*

2.4. Consumption Structure of the Rural Population

The Engel coefficient of rural households reflects the proportion of expenditure on food. A decline in this coefficient signals consumption upgrading, with rising demand for green, high-quality, and personalized agricultural products [18]. This demand shift drives agricultural production toward ecological and brand-oriented transformation, compelling the adoption of technologies such as intelligent breeding and precision traceability to meet quality and safety requirements [19].

Meanwhile, diversified consumption patterns have fostered leisure agriculture and rural tourism integration, expanding agricultural scenarios and creating opportunities for digital agriculture and smart tourism technologies. These developments promote the advancement of agricultural new-quality productivity from the demand side [20,21].

H5a: *A lower Engel coefficient (consumption upgrading) enhances ANQP by stimulating demand for high-quality and green products.*

H5b: *A lower Engel oefficient inhibits ANQP in some regions by inducing consumption outflow and constraining local agricultural transformation.*

3. Materials and Methods

3.1. Measurement of Agricultural New-Quality Productivity

The core explanatory variable in this study is agricultural new-quality productivity. Its measurement follows the framework of Jia Kang and Guo Qirui [22], which emphasizes three fundamental factors—laborers, objects of labor, and means of labor—while incorporating the characteristics of "new" productivity. Accordingly, an indicator system for agricultural new-quality productivity was constructed (see Table 1). The entropy-weight method was used to assign indicator weights, and weighted calculations were applied to derive the agricultural new-quality productivity index for each province from 2013 to 2022.

Table 1. Indicator System for Agricultural New-Quality Productivity.

Target	Criterion	Primary	Secondary	Tertiary	Method	Attr.
Agricultural New-Quality Productivity	Labor	Labor Productivity	Economic Income	Farmers' Disposable Income	Per Capita Disposable Income of Rural Residents (CNY/person)	+
			Agricultural Output	Per Capita Agricultural Added Value	Agricultural, Forestry, Animal Husbandry, and Fishery Added Value ÷ Rural Population (CNY/person)	+
			Employment Structure	Non-Agricultural Employment Ratio	1 − (Number of Primary Industry Employees ÷ Total Rural Employment) (%)	+
		Labor Quality	Educational Attainment	Average Years of Education of Rural Residents	Average Years of Education per Rural Resident (years)	+
			Education Funding Intensity	Education Funding Intensity	Education Expenditure × (Total Output Value of Agriculture, Forestry, Animal Husbandry, and Fishery ÷ Regional GDP) ÷ Total Fiscal Expenditure (%)	+
		Labor Spirit	Innovation Spirit	Full-Time Equivalent of Agricultural R&D Personnel	Number of R&D Researchers × (Total Output Value of Agriculture, Forestry, Animal Husbandry, and Fishery ÷ Regional GDP) (persons)	+
	Means of Labor	Physical Means of Labor	Infrastructure	Agricultural Mechanization Level	Total Power of Agricultural Machinery (KW)	+
				Rural Hydropower Station Level	Number of Rural Hydropower Stations (units)	+
				Investment Intensity in Production Equipment	Investment in Production Equipment ÷ Total Fixed Assets Investment (%)	+

Table 1. *Cont.*

Target	Criterion	Primary	Secondary	Tertiary	Method	Attr.
Agricultural New-Quality Productivity	Means of Labor	Physical Means of Labor	Resource Output Level	Land Productivity	Total Agricultural Output Value ÷ Crop Planting Area (CNY/hectare)	+
				Agricultural Output Ratio	Added Value of Agriculture, Forestry, Animal Husbandry, and Fishery ÷ Total Output Value of Agriculture, Forestry, Animal Husbandry, and Fishery (%)	+
			Resource Utilization Level	Agricultural Machinery Power per Unit Cultivated Land	Total Power of Agricultural Machinery ÷ Cultivated Land Area (KW/hectare)	+
				Proportion of Water-Saving Irrigated Area	Water-Saving Irrigated Area ÷ Effective Irrigated Area (%)	+
		Immaterial Means of Labor	Technological Innovation Level	Agricultural Science and Technology Expenditure	Internal R&D Expenditure × (Total Output Value of Agriculture, Forestry, Animal Husbandry, and Fishery ÷ Regional GDP) (CNY)	+
				Agricultural Fiscal Input Intensity	Fiscal Expenditure on Agriculture, Forestry, and Water ÷ Total Fiscal Expenditure (%)	+
	Object of Labor	Non-Physical Object of Labor	Informatization Level	Digital Information	Number of Rural Broadband Users (households)	+
				Green Production Outcomes	Actual number of rural cable TV users ÷ total number of households (%)	+
		Green Physical Object of Labor	Green Production	Green Production Outcomes	Number of Green Food Certified Products in the Year (units)	+
			Environmental Pollution	Fertilizer Consumption per Unit	Fertilizer Usage ÷ Crop Planting Area (kg/hectare)	−
				Pesticide Consumption per Unit	Pesticide Usage ÷ Crop Planting Area (kg/hectare)	−
				Agricultural Film Consumption per Unit	Agricultural Plastic Film Usage ÷ Crop Planting Area (kg/hectare)	−
			Green Ecology	Forest Coverage Rate	Forest Coverage Rate (%)	+

Note: "Attr." denotes Attribute. In the last column, parentheses are used for calculation formulas. The measurement units of the variables are indicated in an additional pair of parentheses at the end.

3.2. Data Sources

Following the data selection strategies of relevant scholars and data availability, this study selects 30 provincial-level administrative units in mainland China (excluding Hong Kong, Macao, Taiwan, and Tibet) as the research sample for 2013–2022. A ten-year provincial panel dataset is constructed, drawing primarily on the China Statistical Yearbook, China Rural Statistical Yearbook, China Environmental Statistical Yearbook, Green Food Statistical Yearbook, the CCAD and CNRDS databases, and provincial statistical bulletins. Linear interpolation is applied to estimate the few missing values [23].

3.3. Model Specification

This study examines the differentiated effects of China's demographic structure on the development of agricultural new-quality productivity. To this end, the following model is specified. A panel data regression is employed to control for heterogeneity across regions and over time. By incorporating fixed effects, the model addresses potential biases from province-specific characteristics (e.g., economic development, resource endowment) and time-specific changes (e.g., policy shifts, market fluctuations), thereby ensuring robust results [24].

In determining the functional form, this study adopts a linear specification grounded in both theoretical reasoning and empirical applicability. The linear structure facilitates a direct and intuitive interpretation of the marginal effects and directions (positive or negative) of demographic factors on agricultural new-quality productivity (ANQP), as posited in Hypotheses H1a–H5b, and aligns with the conceptual framework of this research. Furthermore, because ANQP is a composite index constructed using the entropy-weight method, it represents a proportional measure of innovation-driven productivity rather than a physical output. This characteristic makes the linear specification particularly suitable for capturing continuous variations in ANQP across regions and over time. The modeling approach adopted here is consistent with the standard econometric framework of Wooldridge [25] and has been widely applied in recent empirical analyses of agricultural and demographic productivity [26,27], providing a robust and credible basis for identifying the demographic determinants of ANQP.

In addition, all variables are log-transformed to reduce heteroscedasticity and the influence of extreme values [28], enhance estimation robustness, and allow more intuitive interpretation of the relative effects of demographic structure on agricultural new-quality productivity. For illustrative purposes, when estimating Equation (1), if the coefficient of the rural elderly dependency ratio is -0.005, it implies that a one-percentage-point increase in the aging ratio is associated with an approximate 0.5% decline in ANQP, holding other factors constant. This example demonstrates how the estimated coefficients can be interpreted in terms of the magnitude and direction of demographic effects on agricultural new-quality productivity.

$$ln\text{ANQP}_{it} = \alpha_0 + a_1 lnRP_{it} + \alpha_2 lnx_{it} + \mu_i + \theta_t + \varepsilon_{it} \quad (1)$$

In Equation (1), α_0 denotes the constant term; RP_{it} represents the rural demographic structure of province i in year t; ANQP_{it} denotes the agricultural new-quality productivity index of province i in period t; x_{it} represents the control variables; μ_i captures individual-specific effects that do not vary over time; θ_t captures time-specific effects that do not vary across individuals; ε_{it} is the random error term; a_1 and α_2 denote the coefficient to be estimated.

3.4. Variable Selection

3.4.1. Dependent Variable

The dependent variable is the agricultural new-quality productivity index, as defined in Section 2.1.

3.4.2. Core Explanatory Variable

The core explanatory variable in this study is the rural demographic structure. Following previous research, it is categorized into four dimensions: age structure, gender structure, household structure, and consumption structure [29]. The measurement methods for each dimension are presented in Table 2.

3.4.3. Control Variables

Based on prior studies [30–33], the control variables include several macroeconomic and structural factors that may indirectly affect agricultural new-quality productivity (ANQP). The control variables include:

Table 2. Variable Definitions and Measurement Methods.

Variable Name	Variable Definition	Measurement Method
Age Structure	Rural Child Dependency Ratio	(Number of rural children aged 0–14 ÷ Number of rural working-age population aged 15–64) × 100% (%)
	Rural Elderly Dependency Ratio	(Number of rural elderly aged 65 and above ÷ Number of rural working-age population aged 15–64) × 100% (%)
Gender Structure	Rural Gender Ratio	(Number of rural males ÷ Number of rural females) × 100 (%)
Household Structure	Average Rural Household Size	Total rural household population ÷ Number of rural households (persons/household)
Consumption Structure	Engel Coefficient of Rural Households	(Total food expenditure of rural households ÷ Total consumption expenditure of rural households) × 100% (%)

Note: In the last column, parentheses are used for calculation formulas. The measurement units of the variables are indicated in an additional pair of parentheses at the end.

The level of financial development is measured by the ratio of the balance of deposits and loans of regional financial institutions to regional GDP, reflecting the availability of financial resources that facilitate agricultural investment and technological innovation. The dependence on agricultural product imports and exports is measured by the ratio of the total value of agricultural product imports and exports to the value added of the primary industry; this variable captures the degree of integration into external markets, where trade openness can enhance efficiency and knowledge spillovers. The urban–rural expenditure gap reflects the consumption disparity between urban and rural residents, which may influence demand-driven agricultural upgrading and the diffusion of innovative products. The level of economic development is measured by regional GDP per capita, representing the overall economic capacity and infrastructure level that support technology adoption and innovation diffusion. Finally, the labor force level is measured as the natural logarithm of the number of employed persons, indicating the scale of available human capital, which affects technological absorption and innovation capacity in agricultural production.

3.4.4. Descriptive Statistics

According to Table 3, the mean value of agricultural new-quality productivity is 0.292, with a standard deviation of 0.081, a minimum of 0.145, and a maximum of 0.529. The average rural child dependency ratio is 26.603, the elderly dependency ratio is 19.298, the gender ratio is 107.06, the average household size is 3.143, and the mean Engel coefficient is 32.498. The remaining control variables are financial development, agricultural import–export dependence, the urban–rural expenditure gap, economic development, and the labor force. These indicators vary significantly nationwide, reflecting substantial regional disparities in economic development and resource endowments.

Table 3. Summary Statistics.

Variable Name	Obs	Mean	Std. Dev.	Min	Max
Agricultural New-quality Productivity	300	0.292	0.081	0.145	0.529
Rural Child Dependency Ratio	300	26.603	8.313	6.26	44.45
Rural Elderly Dependency Ratio	300	19.298	7.095	7.69	45.8
Rural Gender Ratio	300	107.06	4.68	97.46	132.38

Table 3. *Cont.*

Variable Name	Obs	Mean	Std. Dev.	Min	Max
Average Rural Household Size	300	3.143	0.439	1.96	4.02
Engel Coefficient of Rural Households	300	32.498	4.526	23.8	49.5
Level of Financial Development	300	3.54	1.076	1.912	7.618
Dependence on Agricultural Product Imports and Exports	300	66.445	224.459	0.04	2066.285
Urban–Rural Expenditure Gap	300	2.039	0.276	1.492	2.832
Level of Economic Development	300	64,540.822	30,918.794	23,151	190,313
Labor Force Level	300	2210.266	1283.558	486.89	4903.2

4. Results and Discussion

4.1. Current Status of Agricultural New-Quality Productivity

4.1.1. Static Measurement Results of Agricultural New-Quality Productivity

Before presenting the empirical results, it is necessary to clarify the interpretation of the ANQP index. The index ranges from 0 to 1: values closer to 0 indicate a low level of new-quality productivity, where agriculture remains dependent on traditional factor inputs with limited technological and organizational innovation, while values closer to 1 reflect a high level of new-quality productivity characterized by digitalization, intelligent technologies, green production, and innovation-driven development.

According to Figure 2 and Table 4 China's agricultural new-quality productivity index rose from 0.248 in 2013 to 0.349 in 2022, exhibiting a stage-based upward trajectory. While the absolute increase in the ANQP index from 0.25 to 0.35 may seem modest, it corresponds to a relative growth of approximately 40% over the past decade. For a multidimensional composite index, such progress is considerable, as it reflects not only the adoption of new technologies but also deeper structural transformations within agricultural development. This sustained upward trajectory suggests that China's agriculture has advanced from a relatively low level of innovation-driven productivity toward a more mature stage, carrying important implications for agricultural modernization and the improvement of rural well-being. Previous studies have shown that improvements in agricultural technology adoption and organizational innovation can significantly increase farm income [34], enhance resource-use efficiency [35], and promote environmentally sustainable practices [36,37], thereby translating productivity gains into tangible benefits for rural households.

Specifically, 2013–2015 marked the initial cultivation stage with slow growth; 2016–2019 represented a rapid growth phase; and 2020–2022 saw further acceleration, driven by digital transformation and the agglomeration of innovation factors.

Leading provinces—such as Guangdong, Jiangsu, and Shandong—maintained relatively high and steadily rising levels of agricultural new-quality productivity. For example, Guangdong's index rose from 0.382 in 2013 to 0.529 in 2022; Jiangsu's increased from 0.336 to 0.455; and Shandong's climbed from 0.373 to 0.464.

Provinces with fluctuating trends—such as Henan and Hubei—experienced volatility in their development. Henan's index rose from 0.275 in 2013 to 0.396 in 2022, while Hubei's fluctuated between increases and decreases, ending at 0.397.

Lagging provinces—such as Ningxia and Qinghai—maintained low levels of agricultural new-quality productivity with limited growth, constrained by geography and weaker economic foundations. From 2013 to 2022, Ningxia's index ranged from 0.150 to 0.224, while Qinghai's fluctuated between 0.152 and 0.198.

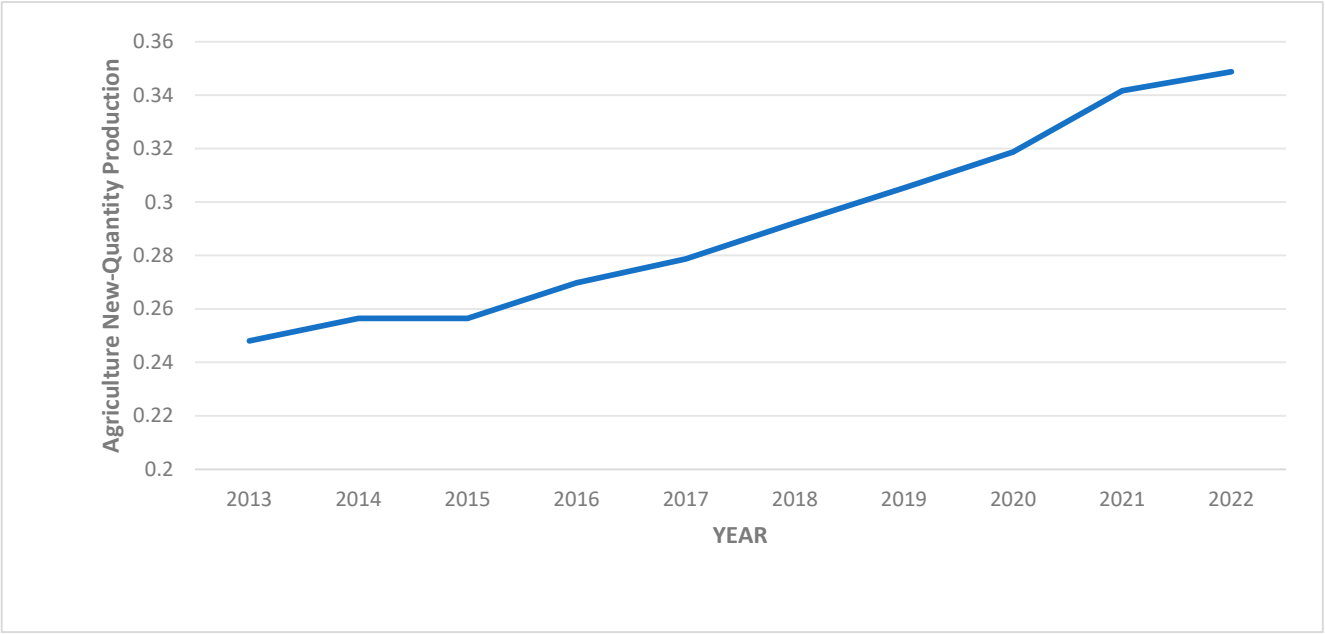


Figure 2. Trend of Agricultural New-Quality Productivity in China, 2013–2022.

Table 4. Static Measurement Results of Agricultural New-Quality Productivity, 2013–2022.

Provinces	Year									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Beijing	0.239	0.244	0.255	0.265	0.276	0.282	0.289	0.289	0.306	0.299
Tianjin	0.145	0.148	0.151	0.159	0.173	0.182	0.186	0.195	0.221	0.218
Hebei	0.286	0.292	0.297	0.288	0.296	0.316	0.332	0.348	0.37	0.389
Shanxi	0.2	0.212	0.223	0.225	0.234	0.243	0.214	0.226	0.262	0.242
Inner Mongolia	0.211	0.221	0.226	0.225	0.226	0.239	0.239	0.26	0.27	0.268
Liaoning	0.261	0.261	0.266	0.264	0.262	0.268	0.274	0.259	0.274	0.275
Jilin	0.237	0.24	0.233	0.229	0.228	0.235	0.235	0.263	0.279	0.265
Heilongjiang	0.32	0.305	0.34	0.338	0.354	0.362	0.368	0.391	0.423	0.395
Shanghai	0.174	0.183	0.182	0.175	0.182	0.195	0.208	0.193	0.194	0.209
Jiangsu	0.316	0.372	0.347	0.346	0.363	0.369	0.402	0.4	0.457	0.455
Zhejiang	0.336	0.31	0.351	0.354	0.363	0.386	0.391	0.396	0.447	0.447
Anhui	0.237	0.324	0.265	0.273	0.288	0.306	0.313	0.345	0.363	0.389
Fujian	0.327	0.31	0.348	0.363	0.372	0.39	0.414	0.411	0.426	0.454
Jiangxi	0.271	0.234	0.288	0.305	0.315	0.322	0.328	0.346	0.364	0.381
Shandong	0.373	0.387	0.393	0.39	0.395	0.408	0.412	0.434	0.446	0.464
Henan	0.275	0.297	0.29	0.282	0.292	0.307	0.331	0.361	0.395	0.396
Hubei	0.269	0.306	0.283	0.289	0.3	0.305	0.325	0.353	0.385	0.397
Hunan	0.293	0.367	0.312	0.328	0.339	0.361	0.389	0.415	0.432	0.447
Guangdong	0.382	0.288	0.385	0.394	0.417	0.431	0.466	0.491	0.512	0.529
Guangxi	0.266	0.257	0.296	0.302	0.309	0.322	0.353	0.372	0.401	0.412
Hainan	0.197	0.229	0.219	0.242	0.245	0.263	0.277	0.286	0.31	0.346
Chongqing	0.193	0.247	0.204	0.216	0.226	0.242	0.265	0.292	0.307	0.304
Sichuan	0.32	0.284	0.352	0.358	0.37	0.382	0.394	0.419	0.434	0.462
Guizhou	0.194	0.22	0.237	0.245	0.257	0.28	0.299	0.308	0.329	0.342
Yunnan	0.231	0.221	0.242	0.253	0.272	0.278	0.312	0.323	0.342	0.373
Shaanxi	0.227	0.235	0.239	0.246	0.252	0.272	0.287	0.307	0.319	0.336
Gansu	0.162	0.168	0.191	0.194	0.21	0.231	0.226	0.245	0.267	0.267
Qinghai	0.152	0.155	0.156	0.156	0.168	0.17	0.185	0.181	0.194	0.198
Ningxia	0.15	0.175	0.155	0.172	0.171	0.194	0.183	0.202	0.234	0.224
Xinjiang	0.196	0.203	0.205	0.217	0.208	0.224	0.262	0.249	0.285	0.278

4.1.2. Regional Measurement Results of Agricultural New-Quality Productivity

According to Table 5 and Figure 3, Northeast: From 2013 to 2022, the index fluctuated upward from 0.273 to 0.312. Growth was modest early on, but accelerated after 2018, peaking at 0.325 in 2021 before a slight decline in 2022.

Table 5. Regional Measurement Results of Agricultural New-Quality Productivity, 2013–2022.

Region	Year									
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Northeast	0.273	0.268	0.279	0.277	0.281	0.288	0.292	0.304	0.325	0.312
East	0.267	0.275	0.283	0.287	0.297	0.309	0.321	0.335	0.359	0.366
Central	0.273	0.288	0.29	0.292	0.301	0.313	0.323	0.337	0.361	0.366
West	0.253	0.261	0.269	0.275	0.284	0.298	0.313	0.327	0.35	0.358

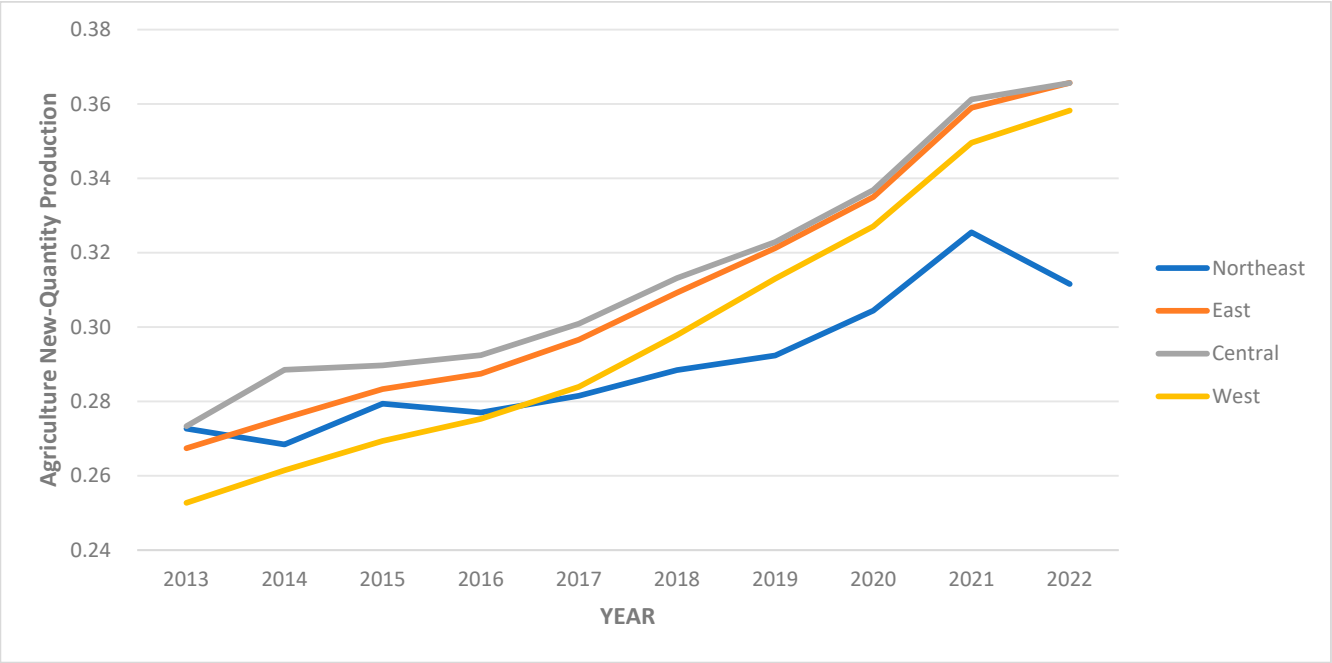


Figure 3. Regional Trends in Agricultural New-Quality Productivity, 2013–2022.

East: The index rose steadily from 0.267 to 0.366, supported by advantages such as a developed economy, strong agricultural R&D, and efficient technology transfer, thus maintaining a leading position nationwide.

Central: The index rose from 0.273 in 2013 to 0.366 in 2022, matching the east. Growth accelerated after 2018, with particularly rapid catch-up between 2020 and 2022.

West: From the lowest value of 0.253 in 2013, the index climbed to 0.358 in 2022. Despite a weak foundation, growth accelerated markedly after 2017, gradually narrowing the gap with other regions.

Overall, agricultural new-quality productivity across China's four economic belts followed an upward trajectory, albeit with differences in stages and levels. The east and central regions accelerated markedly in the later period; the northeast fluctuated; and the west followed a "catch-up" pattern. Early on, the east led while the west lagged; later, the central region caught up with the east, the west approached the forefront, and the northeast showed slight volatility.

4.2. Baseline Regression Results

To examine the relationship between the rural demographic structure and the development of agricultural new-quality productivity, this study employs a fixed-effects model that controls for time trends and individual heterogeneity. Empirical estimations are conducted under two scenarios: without control variables (Column 1) and with control variables (Column 2), as shown in Table 6. This design systematically reveals how different dimensions of the rural demographic structure affect agricultural new-quality productivity.

Table 6. Baseline Regression Results and Robustness Checks.

Variable	(1)	(2)	(3)	(4)
Age Structure 1	0.0498	0.0344	0.0254	−0.00356
	(0.047)	(0.046)	(0.046)	(0.050)
Age Structure 2	−0.115 ***	−0.0978 ***	−0.0834 **	−0.114 ***
	(0.037)	(0.037)	(0.037)	(0.040)
Gender Structure	−0.252 *	−0.334 **	−0.317 **	−0.261 *
	(0.137)	(0.136)	(0.135)	(0.145)
Household Structure	0.03	0.0275	0.0431	0.129
	(0.112)	(0.110)	(0.110)	(0.118)
Consumption Structure	−0.227 ***	−0.148 *	−0.142 *	−0.182 **
	(0.084)	(0.085)	(0.085)	(0.091)
Constant	0.672	−0.794	−1.066	−0.0167
	(0.829)	(0.906)	(0.903)	(0.971)
Observations	300	300	300	300
Number of id	30	30	30	30
R-squared	0.826	0.836	0.835	0.793
Control Variables	NO	YES	YES	YES
Time Fixed Effects	YES	YES	YES	YES
Individual Fixed Effects	YES	YES	YES	YES

Note: (1) * at the 10% level, ** at the 5% level, and *** at the 1% level; (2) *t*-values are in parentheses; (3) For brevity, "Age Structure 1" and "Age Structure 2" in the table denote the Rural Child Dependency Ratio and the Rural Elderly Dependency Ratio, respectively.

4.2.1. Impact of Age Structure

For the child dependency ratio, the regression coefficients in Columns 1 and 2 are 0.0498 and 0.0344, respectively, and neither is statistically significant ($p > 0.1$). The results show that Hypotheses H1a and H1b are not supported. This suggests that, at the national level, the rural child dependency ratio has no direct or significant effect on agricultural new-quality productivity. The child population is not part of the agricultural labor force, and its influence operates through long-term human capital accumulation. On the one hand, educational investment and early skill development require more than a decade before transforming into agricultural innovation talent (e.g., returning youth entrepreneurs or technology developers). On the other hand, in the short term, the crowding-out effect of child-rearing on household agricultural investment is weak. Therefore, the effect of the child dependency ratio is long-term and indirect, making it difficult to translate quickly into agricultural new-quality productivity [38].

For the elderly dependency ratio, the coefficients are −0.115 in Column 1 and −0.0978 in Column 2, both significant at the 1% level and negative. The results show that Hypothesis H2a is not supported, while Hypothesis H2b is supported. This indicates that a higher rural elderly dependency ratio significantly inhibits the development of agricultural new-quality productivity. The mechanism works in two ways. First, a higher elderly dependency ratio amplifies the resource crowding-out effect: heavier support burdens force households to allocate more financial and human resources to elderly care—such as medical expenses and daily caregiving—thereby reducing productive agricultural investment, including intelligent machinery and green technologies. Second, a higher elderly dependency ratio

delays technology adoption. A larger share of elderly laborers entails higher learning costs and lower willingness to adopt new agricultural technologies and models, hindering the spread of advanced production methods and slowing the improvement of agricultural new-quality productivity.

4.2.2. Impact of Gender Structure

The gender structure affects agricultural production efficiency and resilience through two channels: "labor division adaptability" and "social resource allocation". The regression coefficients are −0.252 in Column 1 ($p < 0.1$) and −0.334 in Column 2 ($p < 0.05$). The results show that Hypothesis H3a is not supported, while Hypothesis H3b is supported. This indicates that an imbalanced rural gender ratio—specifically, a male proportion deviating from a reasonable range—significantly hinders the development of agricultural new-quality productivity.

The mechanisms operate as follows. First, gender imbalance reduces labor division efficiency. In agricultural production, men tend to specialize in heavy labor and machinery operation, while women excel in precision cultivation and agricultural e-commerce [39]. A skewed gender ratio causes "structural mismatches" in the labor force: an excess of men leads to repetitive, low-efficiency work, while a shortage of women constrains value chain extension, ultimately reducing organizational efficiency.

Second, gender imbalance diverts social resources. It generates marriage-related pressures and social tensions—such as high bride prices and declining family stability [40], that divert household resources away from agricultural development. Funds that could support technological upgrades are instead spent on marriage-related expenses [41], weakening the foundation for fostering agricultural new-quality productivity [42].

4.2.3. Impact of Household Structure

For household structure, the coefficients are 0.03 in Column 1 and 0.0275 in Column 2, neither statistically significant. The results show that Hypotheses H4a and H4b are not supported. This suggests that the current average household size has no significant effect on agricultural new-quality productivity. The possible explanations are as follows.

First, the effect is offset by the diversification of agricultural models in China. Rural household operations are highly diverse: small-scale households offset production shortcomings through socialized services such as machinery-sharing platforms and outsourced plowing, thereby integrating smallholders into modern agriculture. In contrast, large households are constrained by land fragmentation and rising management costs, making it difficult to fully realize economies of scale.

Currently, widespread land fragmentation and the underdevelopment of family farms mean that household size has not yet become a key driver of agricultural new-quality productivity [43,44], thus showing no significant association.

4.2.4. Impact of Consumption Structure

For consumption structure, the coefficient is −0.227 in Column 1 ($p < 0.01$) and −0.148 in Column 2 ($p < 0.1$), both significantly negative. The results show that Hypothesis H5a is not supported, while Hypothesis H5b is supported. This suggests that a decline in the Engel coefficient—indicating consumption upgrading—positively affects agricultural new-quality productivity. The reason is that consumption upgrading shifts demand toward higher quality, greater diversity, and stronger branding (e.g., organic products and specialty processed goods). This shift compels innovation on the production side, driving smart cultivation to enhance quality stability and promoting deep processing to extend the value chain, thereby boosting agricultural new-quality productivity [45,46].

4.3. Robustness Tests

To verify the reliability of the baseline regression results on the relationship between rural demographic structure and agricultural new-quality productivity, robustness checks are conducted (see Table 6), Column 3 applies 1% winsorization to the dependent variable, while Column 4 replaces the dependent variable with a one-period lag of agricultural new-quality productivity. These two strategies assess the stability of the results.

Column 3 shows that the coefficient for the rural child dependency ratio is 0.0254 and remains statistically insignificant ($p > 0.1$). This suggests that the conclusion of no direct significant impact is robust: removing extreme values does not alter its "long-term, indirect effect," and short-term effects remain undetectable. The coefficient for the elderly dependency ratio is -0.0834 ($p < 0.05$), significantly negative. Compared with the baseline result of -0.0978 ($p < 0.01$), the absolute value decreases slightly but remains significant at the 5% level, confirming its robustness. Even after removing extreme values, the mechanisms of resource crowding-out and delayed technology adoption remain unchanged; the slight fluctuation results only from distributional adjustment after winsorization, confirming that the elderly dependency ratio persistently constrains agricultural new-quality productivity. The coefficient for gender structure is -0.317 ($p < 0.01$), still significantly negative as in the baseline regression, confirming the reliability of its effect. The coefficient for household structure is 0.0431, slightly higher than the baseline but still insignificant, confirming the robustness of the "no significant effect" conclusion. Regardless of winsorization, diversified household models and land fragmentation continue to prevent household size from becoming a core driver; removing extreme values does not change this logic. The coefficient for consumption structure is -0.142 ($p < 0.1$), significantly negative. Compared with the baseline, the absolute value declines slightly but remains significant, confirming the robustness of consumption upgrading's positive effect. The demand-driven innovation pathway remains unchanged after removing extreme values, verifying the positive link between consumption structure and agricultural new-quality productivity. Overall, winsorization does not materially change the main conclusions, confirming the robustness of the baseline results.

Column 4 shows that the coefficient for the rural child dependency ratio is -0.00356 and remains insignificant, indicating that its long-term effect is still difficult to capture in a one-period lag framework. The coefficient for the elderly dependency ratio is -0.114 ($p < 0.01$), significantly negative and consistent with the baseline, reinforcing its reliability. The coefficient for gender structure is -0.261 ($p < 0.1$), significantly negative. Compared with Column 2 of the baseline (-0.334, $p < 0.05$), the absolute value decreases but remains significant at 10%, thus, even with a lagged dependent variable, the negative effect persists, confirming the robustness of the gender structure effect. The coefficient for household structure is 0.129 and remains insignificant, confirming the robustness of the "no significant effect" conclusion. Even with a lagged dependent variable, diversified household models and land constraints prevent household size from directly affecting agricultural new-quality productivity. The coefficient for consumption structure is -0.182 ($p < 0.05$), significantly negative. Compared with the baseline (-0.148, $p < 0.1$), the absolute value increases and significance improves (from 10% to 5%), indicating that the positive effect of consumption upgrading has a lagged transmission. Demand-driven agricultural innovation takes time to materialize (e.g., through industrial upgrading and technology adoption), so with a one-period lag, the positive effect becomes more pronounced, confirming the long-term link between consumption structure and agricultural new-quality productivity.

In summary, both robustness tests do not alter the core conclusions of the baseline regression, confirming the stability and reliability of the effects of rural demographic structure on agricultural new-quality productivity.

4.4. Heterogeneity Analysis

To examine the heterogeneous effects of demographic structure on agricultural new-quality productivity across regions, the 30 provinces are grouped into eight comprehensive economic zones following the classification of the Development Research Center of the State Council: Column 1: Northeast Comprehensive Economic Zone (Liaoning, Jilin, Heilongjiang); Column 2: Northern Coastal Comprehensive Economic Zone (Beijing, Tianjin, Hebei, Shandong); Column 3: Eastern Coastal Comprehensive Economic Zone (Shanghai, Jiangsu, Zhejiang); Column 4: Southern Coastal Comprehensive Economic Zone (Fujian, Guangdong, Hainan); Column 5: Middle Reaches of the Yellow River Comprehensive Economic Zone (Shaanxi, Shanxi, Henan, Inner Mongolia); Column 6: Middle Reaches of the Yangtze River Comprehensive Economic Zone (Hubei, Hunan, Jiangxi, Anhui); Column 7: Southwest Comprehensive Economic Zone (Yunnan, Guizhou, Sichuan, Chongqing, Guangxi); and Column 8: Northwest Comprehensive Economic Zone (Gansu, Qinghai, Ningxia, Xinjiang). The regression results for each subsample are reported in Table 7.

Table 7. Heterogeneity Analysis Results.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Age Structure 1	−0.505 **	−0.296 *	0.00972	−0.566	0.148	−0.0461	−0.157	−0.192
	(0.185)	(0.160)	(0.213)	(0.463)	(0.235)	(0.414)	(0.167)	(0.361)
Age Structure 2	−0.0871	0.170 *	−0.0026	0.543	−0.604 ***	−0.088	0.159	−0.129
	(0.185)	(0.086)	(0.171)	(0.306)	(0.173)	(0.477)	(0.205)	(0.193)
Gender Structure	0.257	−0.404 *	−0.114	0.774	−0.124	1.192	−0.703	−1.245 *
	(0.451)	(0.201)	(0.728)	(0.595)	(0.322)	(1.275)	(0.414)	(0.694)
Household Structure	−0.683 *	−0.234	0.105	−0.0827	0.219	−1.218 *	−0.515	−0.123
	(0.311)	(0.256)	(0.576)	(0.630)	(0.589)	(0.593)	(0.409)	(0.491)
Consumption Structure	−0.0032	0.354 *	0.342	1.128 *	−1.265 **	0.788	0.124	−0.501
	(0.261)	(0.190)	(0.431)	(0.514)	(0.554)	(0.682)	(0.213)	(0.299)
Constant	−0.0654	1.117	9.672	4.931	5.610 **	−10.86	4.188	10.71
	(2.530)	(1.957)	(11.760)	(6.340)	(2.528)	(9.277)	(2.959)	(7.100)
Observations	30	40	30	30	40	40	50	40
Number of id	3	4	3	3	4	4	5	4
R-squared	0.963	0.972	0.901	0.957	0.948	0.906	0.955	0.944

Note: (1) * at the 10% level, ** at the 5% level, and *** at the 1% level; (2) *t*-values are in parentheses; (3) For brevity, "Age Structure 1" and "Age Structure 2" in the table denote the Rural Child Dependency Ratio and the Rural Elderly Dependency Ratio, respectively.

4.4.1. Heterogeneity Analysis of Population Age Structure

For the child dependency ratio, the results show a negative effect on agricultural new-quality productivity in both the Northeast and Northern Coastal Comprehensive Economic Zones, with the effect significant in the Northeast (coefficient = −0.505, $p < 0.05$). This suggests that in the Northeast, the rising child-rearing burden crowds out household resources for upgrading agricultural technologies and investment. Combined with low fertility and out-migration trends, this leads to insufficient agricultural labor reserves and weakens the long-term potential for technology transmission and innovation.

In the Middle Reaches of the Yellow River Comprehensive Economic Zone, the coefficient for the elderly dependency ratio is significantly negative (−0.604, $p < 0.01$), indicating that aging exerts the strongest inhibitory effect on agricultural new-quality productivity in this region. This can be attributed to the region's reliance on skilled labor in traditional agriculture, the low willingness of elderly laborers to adopt new technologies, and the crowding-out of productive investment caused by rising elderly support burdens, producing a "double-constraint" effect. By contrast, in the Northern Coastal Comprehensive Economic Zone, the elderly dependency ratio shows a positive coefficient (0.170, $p < 0.1$),

possibly because the region's developed social security system mitigates the crowding-out effect of elderly care on agricultural investment, and because some elderly laborers contribute to the stable operation of family farms.

4.4.2. Heterogeneity Analysis of Population Gender Structure

The impact of gender structure shows notable regional variation. In the Northern Coastal Comprehensive Economic Zone, the coefficient is −0.404 ($p < 0.1$), suggesting that gender imbalance constrains the development of agricultural new-quality productivity. Given the region's higher level of agricultural modernization, women play a key role in product processing, digital management, and agricultural e-commerce. A shortage of female labor reduces efficiency in these areas, disrupting the smooth functioning of modern agricultural value chains.

In the Northwest Comprehensive Economic Zone, the coefficient is −1.245 ($p < 0.1$), significantly negative, indicating that gender imbalance poses a severe constraint on agricultural development. The combination of a male-dominated, heavy-labor-oriented production model and female outmigration causes labor shortages in light mechanization, precision management, and brand operations, thereby suppressing improvements in agricultural new-quality productivity.

4.4.3. Heterogeneity Analysis of Population Household Structure

In the Northeast Comprehensive Economic Zone, the coefficient for household size is −0.683 ($p < 0.1$), significantly negative, indicating that smaller households constrain agricultural new-quality productivity. Slow progress in land transfer and large-scale operations in the Northeast means that small households cannot sustain investments in intelligent and large-scale machinery, leading to high marginal costs and lower production efficiency.

In the Middle Reaches of the Yangtze River Comprehensive Economic Zone, the coefficient for household structure is −1.218 ($p < 0.1$), also significantly negative. This may be due to the region's dominant smallholder economy and underdeveloped socialized service system. Small households cannot effectively offset limited production resources through machinery-sharing or technical outsourcing, leaving them constrained in funding, technology, and management, thereby restricting the development of agricultural new-quality productivity.

4.4.4. Heterogeneity Analysis of Consumption Structure

For consumption structure, the coefficient for the Southern Coastal Comprehensive Economic Zone is 1.128 ($p < 0.1$), significantly positive, indicating that consumption upgrading strongly promotes agricultural new-quality productivity in this region. With the advancement of the Guangdong–Hong Kong–Macao Greater Bay Area and Hainan Free Trade Port, demand for high-end agricultural products, leisure agriculture, and rural cultural tourism has surged. This surge in demand has spurred innovation in smart cultivation, product processing, brand building, and traceability technologies, forming a positive "demand–technology–production" cycle.

By contrast, in the Middle Reaches of the Yellow River Comprehensive Economic Zone, the coefficient for consumption structure is −1.265 ($p < 0.05$), significantly negative. This suggests that consumption upgrading in the region may trigger a "consumption outflow" effect, in which high-quality demand is redirected to external markets. As a result, local agricultural industries fail to transform and upgrade effectively, creating a mismatch between supply and demand and impeding the development of agricultural new-quality productivity [47].

4.5. Discussion

Rather than restating the empirical results, this section emphasizes the broader theoretical and policy implications of the analysis. The heterogeneous effects of the rural demographic structure on agricultural new-quality productivity (ANQP) reveal the dual role of demographic factors in shaping both innovation potential and transformation capacity. While population aging constrains the diffusion of new technologies, improvements in gender balance and consumption upgrading stimulate innovation through diversified participation and market-oriented demand. These findings indicate that demographic transitions have evolved into an endogenous force of agricultural modernization, complementing traditional drivers such as technology and capital.

Furthermore, the results underscore the value of the ANQP index as a policy-oriented evaluation framework. In contrast to gross agricultural output, which primarily measures quantitative expansion, ANQP captures the qualitative transformation of agricultural systems—including technological advancement, resource efficiency, and green development. This perspective aligns closely with China's strategic transition toward innovation-led and sustainability-oriented growth. Therefore, ANQP functions not only as an analytical metric but also as a guiding framework for assessing high-quality agricultural development.

From this perspective, demographic and innovation policies should be designed as mutually reinforcing components of rural revitalization. Strengthening human capital through education, digital literacy, and youth engagement can alleviate the constraints of population aging and enhance the innovation foundation of agriculture. In doing so, this discussion bridges the empirical evidence with the policy recommendations presented in the following section.

5. Conclusions and Implications

5.1. Main Conclusions

Based on panel data for 30 provinces in China (excluding Hong Kong, Macao, Taiwan, and the Tibet Autonomous Region) from 2013 to 2022, obtained from authoritative sources such as the China Statistical Yearbook and the China Rural Statistical Yearbook, this study employs a fixed-effects model, the entropy-weight method, robustness tests, and heterogeneity analysis to examine the relationship between rural demographic structure and agricultural new-quality productivity.

The findings reveal that while China's agricultural new-quality productivity has shown an overall steady upward trend, it is profoundly shaped by the characteristics of the rural demographic structure. Specifically, accelerated population aging significantly hinders agricultural new-quality productivity; gender imbalance undermines labor division efficiency and technological innovation capacity; consumption upgrading serves as an important driver of improvement; and changes in household structure currently exert no significant effect.

The regional heterogeneity analysis further indicates that the impacts of demographic structure vary considerably across regions. In the Northeast, both a higher child dependency ratio and a smaller household size suppress agricultural productivity. In the Middle Reaches of the Yellow River, the negative effect of aging is most pronounced, while consumption upgrading leads to a "consumption outflow" problem. In the Northern Coastal region, gender imbalance significantly hampers the functioning of agricultural value chains. In the Southern Coastal region, consumption upgrading markedly promotes improvements in agricultural new-quality productivity. In the Middle Reaches of the Yangtze River, a smaller household size constrains the application of agricultural technologies and the release of production efficiency. In the Northwest, a high male proportion limits women's roles in precision management and brand development. By contrast, in the Eastern Coastal

and Southwest regions, the effects of demographic structure across all dimensions are insignificant, possibly because agriculture accounts for a smaller share of the regional economy and relies more on capital and external resource inputs.

Overall, the above findings not only provide empirical evidence of the differentiated influence of the rural demographic structure on agricultural new-quality productivity (ANQP) but also contribute to the existing literature from multiple dimensions. Conceptually, this study extends the analytical framework of agricultural productivity by embedding the demographic structure within the paradigm of innovation-driven and quality-oriented development, thereby enriching the theoretical understanding of agricultural modernization. Empirically, it applies and further validates the ANQP measurement system established in prior research using a comprehensive provincial panel dataset, confirming its effectiveness in examining the demographic–innovation nexus at the regional level. Theoretically, by proposing and empirically testing a set of competing hypotheses (H1a–H5b), the study offers a structured explanation of how demographic transitions can simultaneously foster and constrain innovation in agriculture. Moreover, the identification of regional heterogeneity underscores the complexity and diversity of demographic impacts, providing new insights for designing differentiated policy strategies that align population transformation with innovation-oriented agricultural development. Collectively, these contributions advance the explanatory framework of agricultural development studies and offer valuable guidance for policy formulation under China's high-quality development strategy.

5.2. Policy Implications

5.2.1. Address Rural Aging and Promote Age-Friendly Agricultural Technology Innovations

In response to the inhibitory effect of a rising elderly dependency ratio on agricultural new-quality productivity, efforts should focus on accelerating the development of lightweight and intelligent agricultural machinery suitable for elderly laborers, as well as promoting simple digital management platforms. At the same time, improving rural pension and healthcare systems can reduce the household burden of elderly care, free up productive investment, and enhance the efficiency of agricultural technology application.

5.2.2. Optimize Gender Structure and Enhance Women's Participation and Division-of-Labor Efficiency in Agriculture

To address the decline in division-of-labor efficiency caused by gender imbalance, policies should support women's participation in agricultural technology training, e-commerce operations, and agricultural enterprise management. Leveraging women's strengths in precision management, quality control, and brand building can foster more balanced labor division and promote coordinated development across the agricultural industry chain.

5.2.3. Improve the Socialized Service System and Promote Innovation in Household Operation Models

To mitigate the constraints of smaller household size on agricultural new-quality productivity, agricultural socialized services should be vigorously developed, including machinery-sharing, entrusted farming services, and joint plowing and planting models, in order to reduce technology application costs for smallholders. Simultaneously, land transfer mechanisms should be improved, and appropriately scaled agricultural entities should be cultivated to enhance production efficiency and strengthen the foundation for technology dissemination.

5.2.4. Promote the Coupling of Consumption Upgrading and the Agricultural Supply System

To fully harness the driving effect of consumption upgrading on agricultural new-quality productivity, efforts should focus on fostering green and organic agricultural products, devel-

oping rural leisure tourism, and integrating agriculture with cultural and tourism industries. At the same time, smart agriculture and brand-oriented agriculture should be advanced to improve the adaptability of the agricultural supply system to high-quality and diversified market demand, thereby forming a virtuous "demand–technology–production" cycle.

6. Limitations

While this study provides new insights into the relationship between rural demographic structure and agricultural new-quality productivity (ANQP), several aspects could be further improved in future research. First, the measurement of ANQP, based on the entropy-weight method and provincial-level indicators, could be enriched by incorporating micro-level data to better reflect technological and organizational innovations at the farm level. Second, the analysis adopts a linear model to quantify the effects of demographic factors on ANQP across regions and over time; however, possible nonlinear or threshold effects—especially regarding population aging and urban–rural disparities—could be explored in future studies. Third, although key control variables were selected following the theoretical and empirical literature, additional factors such as institutional quality, environmental regulation, or digital infrastructure could be incorporated to refine the model. Finally, the study focuses on provincial panel data from 2013 to 2022; expanding the temporal or spatial scope, for example, through county-level or cross-country comparisons, would provide further validation and broader implications. Finally, as the ANQP index is constructed from multiple proxy indicators, certain components—such as digitalization and innovation—may not fully capture their theoretical connotations, which could limit its precision as a decision-making indicator. Future studies could refine these measurements by incorporating more direct or micro-level indicators. Despite these limitations, this study offers a robust empirical foundation for understanding the demographic determinants of innovation-driven agricultural transformation in China.

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