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The Impact of New Quality Productive Forces on Green Total Factor Productivity: An Empirical Analysis Based on Provincial Panel Data

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Abstract: *New quality productive forces, characterized by the enhancement of total factor productivity, reflect the standards of contemporary advanced productive forces and embody the core demands of the new development paradigm and high-quality growth. Based on this, the paper selects panel data from 30 Chinese provinces between 2010 and 2019 and utilizes the green total factor productivity index, which accounts for undesirable outputs, to explore the impact and mechanisms of new quality productive forces on green total factor productivity. The results indicate that new quality productive forces significantly enhance green total factor productivity, and this conclusion is further confirmed through a series of robustness checks. Further research finds that the upgrading of industrial structure plays a mediating role in the process, while the agglomeration of high-tech industries and specialized agglomeration of productive service industries act as moderating variables that enhance the positive impact of new quality productive forces on green total factor productivity. Moreover, the impact of new quality productive forces on green total factor productivity exhibits significant regional heterogeneity. Based on these findings, the paper proposes several policy recommendations aimed at fostering the development of new quality productive forces and improving green total factor productivity.*

Keywords: *New Quality Productive Forces; Green Total Factor Productivity; Industrial Structure Upgrading; Industrial Agglomeration*

1. Introduction

With technology as the primary driver of productivity[1] , the concept of "new quality productive forces" (NQPF), introduced in 2023[2] , marks a paradigm shift. It represents a qualitative leap driven by disruptive breakthroughs[3] , leveraging new factors like data[4] in a fundamental transition from a growth model dependent on factor quantity to one reliant on innovation quality[5] , thereby abandoning traditional reliance on resource scale[6].

This shift is particularly critical for China, where environmental constraints necessitate a pivot to high-quality development[7] , making Green Total Factor Productivity (GTFP) a key metric for balancing economic and environmental goals[8]. As NQPF is intrinsically linked to enhancing productivity through sustainable development[9] , this paper measures GTFP considering undesirable outputs to explore whether NQPF effectively promotes its growth and through what mechanisms.

2. Theoretical Analysis and Hypotheses

High technology is a core element of new quality productive forces[10]. Driven by intellectual capital, high-tech industries enhance resource efficiency and are inherently aligned with environmental objectives, making them globally strategic sectors[11]. They foster green innovation by developing and deploying clean technologies, a process influenced by the market environment, government funding, and the variable impact of R&D investment across different firm scales[12]. By reducing emissions and promoting a low-carbon economy, these industries are pivotal for sustainable development, leading us to propose Hypothesis 1:

Hypothesis 1: The enhancement of new quality productive forces significantly promotes the growth of green total factor productivity.

Industrial structure upgrading involves a strategic shift towards high-value, technologically advanced,

ISSN 2616-5902 Vol. 7, Issue 7: 41-49, DOI: 10.25236/AJBM.2025.070706

and sustainable sectors. New quality productive forces (NQPF), particularly those rooted in artificial intelligence and internet technologies, drive this transformation. Through deep integration with traditional industries, NQPF enhances operational efficiency and market competitiveness[13] , leading to more effective resource allocation and improved environmental performance[14].

This evolution towards an intelligent and digitized economy helps overcome traditional constraints, aligning industrial development with the objectives of high-quality growth. Thus, we propose Hypothesis 2:

Hypothesis 2: New quality productive forces enhance green total factor productivity by promoting the upgrading of industrial structures.

Industrial agglomeration is a key mechanism for cultivating new quality productive forces (NQPF). The clustering of high-tech industries is particularly crucial, as it concentrates innovation resources and facilitates knowledge spillovers that accelerate green technology development[15][16]. The agglomeration of productive services provides further support, with specialized clusters offering economies of scale and diversified clusters fostering disruptive, cross-industry innovation[17][18] [19][20]. As these agglomeration patterns are theorized to amplify the efficacy of NQPF, they are expected to strengthen its positive impact on green productivity. Based on this theoretical framework, we propose Hypotheses 3 and 4:

Hypothesis 3: The agglomeration of high-tech industries can promote the development of new quality productive forces, thereby affecting green total factor productivity.

Hypothesis 4: The agglomeration of productive services, whether specialized or diversified, plays a facilitating role in the development of new quality productive forces, significantly impacting the enhancement of green total factor productivity.

3. Model Specification and Variable Description

3.1 Model Construction

To examine the impact of new quality productive forces on green total factor productivity, the following panel fixed-effects model is constructed:

$$GTFP_{it} = \alpha_0 + \alpha_1 prod_{it} + \alpha_2 C_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (1)$$

In this model, i represents the province, and t denotes the year. $GTFP_{it}$ represents the dependent variable, green total factor productivity, while $prod_{it}$ indicates new quality productive forces. C_{it} represents a set of control variables. μ_i refers to the individual fixed effects, ν_t captures time effects, and ϵit denotes the random disturbance term.

To examine the mediating role of industrial structure upgrading in the relationship between new quality productive forces and green total factor productivity, the following mediation effect model is constructed:

$$M_{it} = \beta_0 + \beta_1 prod_{it} + \beta_2 C_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (2)$$

$$GTFP_{it} = \gamma_0 + \gamma_1 prod_{it} + \gamma_2 M_{it} + \gamma_3 C_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (3)$$

In equations (2) and (3), M_{it} represents the mediating variable, which is the upgrading of the industrial structure, while the definitions of the other variables remain consistent with equation (1).

To examine the moderating effect of industrial agglomeration on the relationship between new quality productive forces and green total factor productivity, the following moderating effect model is constructed:

$$GTFP_{it} = \theta_0 + \theta_1 prod_{it} + \theta_2 aggl_{it} + \theta_3 prod_{it} * aggl_{it} + \theta_4 C_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (4)$$

In equation (4), $aggl_{it}$ represents the moderating variable, which includes the agglomeration of productive services and high-tech industries. The term $prod_{it} * aggl_{it}$ denotes the interaction term, and this model primarily examines the coefficient θ_3 of the interaction term.

ISSN 2616-5902 Vol. 7, Issue 7: 41-49, DOI: 10.25236/AJBM.2025.070706

3.2 Variable Definition and Explanation

3.2.1 Dependent Variable

Provincial Green Total Factor Productivity (GTFP). This study measures provincial Green Total Factor Productivity (GTFP) using a robust methodological framework. Specifically, we employ a non-radial, non-oriented super-efficiency Epsilon-Based Measure (EBM) model that incorporates undesirable outputs, in conjunction with the Global Malmquist-Luenberger (GML) index. This combined approach[21] overcomes the limitations of traditional indices to provide a more reliable and temporally consistent measure. The model's inputs include labor, capital, and energy, with capital stock estimated via the perpetual inventory method (10.96% depreciation) and energy represented by water supply and electricity consumption. Outputs are categorized as desirable (real regional GDP) and undesirable (sulfur dioxide and chemical oxygen demand emissions). To eliminate price effects, all monetary variables were adjusted to constant 2000 prices using the appropriate deflators. The specific indicators for measuring green total factor productivity are shown in Table 1:

Table 1 Green Total Factor Productivity

Input Indicators	Urban Employment
	Capital Stock (base year 2000) Calculated using the Perpetual Inventory Method
	Total Water Supply (100 million cubic meters)
	Electricity Consumption (100 million kilowatt-hours)
Desirable Output	Real GDP (base year 2000)
Undesirable Outputs	Sulfur Dioxide Emissions (thousand tons)
	Chemical Oxygen Demand Emissions (ten thousand tons)

3.2.2 Core Explanatory Variable

New quality productive forces. Following Han et al. (2024)[22] and Lu et al. (2024)[23], we measure New Quality Productive Forces using a set of indicators reflecting three core factors: "new laborers," "new labor materials," and "new labor objects." After applying logarithmic transformations to address data heterogeneity, we employed principal component analysis (PCA) to construct a single composite index. The specific indicators are shown in Table 2:

Table 2 New Quality Productive Forces

New Laborers	Number of Universities Ranked Within Top (%) in QS Rankings (units)
	Number of 985/211/Double First-Class Universities (units)
	Proportion of Urban Employees in Information Transmission, Software, and IT Services (%)
	Full-Time Equivalent of R&D Personnel in High-Tech Industries (person-years)
New Labor Materials	Robot Index (-), following the methodology of Kang et al. (2021)[24]
	Software Business Revenue (ten thousand yuan)
	E-Commerce Sales Volume (hundred million yuan)
New Labor Objects	Proportion of New Energy Power Generation (%)
	Number of Internet Access Ports (ten thousand units)
	Cable Length (kilometers)
	Number of Patent Applications Accepted (items)
	Expenditure on New Product Development (ten thousand yuan)
	Transaction Volume in Technology Market (hundred million yuan)
	Total Volume of Telecommunications Services (hundred million yuan)
	Sales Revenue from New Products (ten thousand yuan)

3.2.3 Mediating Variable

Following Gan Chunhui et al. (2011)[25], the Upgrading of Industrial Structure (TS) is quantified as the ratio of tertiary to secondary sector value added, with a higher value indicating a more advanced, service-oriented economy.

3.2.4 Moderating Variables

Following Lu Yuxiu (2024)[26], High-Tech Industry Agglomeration (high) is quantified using a location quotient, representing the ratio of provincial high-tech enterprises to the national total of large-

ISSN 2616-5902 Vol. 7, Issue 7: 41-49, DOI: 10.25236/AJBM.2025.070706

scale industrial enterprises. A higher value indicates greater agglomeration.

Agglomeration of Productive Services:

Following the methodology of Ezcurra et al.[27], we measure Specialized Agglomeration of Productive Services(prof) using their specialization index, where a higher value of this indicator indicates a greater level of specialized agglomeration in the productive services sector.

Following Han Feng et al. (2014)[28], we measure Diversified Agglomeration of Productive Services(mul) using their diversification index, where a higher value of this indicator indicates a greater level of diversified agglomeration in the productive services sector.

3.2.5 Control Variables

Based on existing research and literature, the following indicators are selected as control variables in this study: Environmental Regulation, Foreign Direct Investment, Government Funding, Enterprise Innovation.

3.3 Data Sources

This study focuses on 30 provinces in Chinese mainland, for the period from 2010 to 2019. The data are sourced from the *China Labor Statistical Yearbook*, *China Electric Power Yearbook*, *China High-Tech Industry Statistical Yearbook*, *China Statistical Yearbook*, and robot data published by the *International Federation of Robotics* (IFR). Missing data were supplemented using interpolation methods.

4. Empirical Analysis

4.1 Baseline Regression Results

As shown in Table 3, the baseline regression analysis confirms that new quality productive forces have a robustly positive and highly significant impact on green total factor productivity, supporting Hypothesis 1. This effect is attributable to high-tech industries, which leverage advanced technologies and skilled talent to enhance resource efficiency while simultaneously spurring the development and adoption of green innovations like clean production techniques.

Table 3 Baseline Regression

	(1)	(2)	(3)	(4)
prod	0.0609***	0.0607***	0.0650***	0.0649***
	(0.0097)	(0.0096)	(0.0091)	(0.0092)
gov	-0.0001***	-0.0001***	-0.0001***	-0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ent		-0.0085***	-0.0062**	-0.0063**
		(0.0031)	(0.0029)	(0.0030)
fdi			-0.4890***	-0.4915***
			(0.0887)	(0.0900)
env				0.0003
				(0.0016)
_cons	0.9260***	0.9560***	0.9542***	0.9514***
	(0.0126)	(0.0166)	(0.0157)	(0.0226)
N	300	300	300	300
adj. R^2	0.6339	0.6429	0.6794	0.6782

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.2 Mediation Effect Analysis

Table 4 confirms that industrial structure upgrading partially mediates the positive impact of new quality productive forces on green total factor productivity. The mechanism operates as new quality productive forces drive this upgrading by integrating advanced technologies into traditional industries, thereby enhancing production efficiency and product value. This process, supported by prior research[29] [30] , represents a key pathway through which technological innovation translates into improved green economic performance.

ISSN 2616-5902 Vol. 7, Issue 7: 41-49, DOI: 10.25236/AJBM.2025.070706

Table 4 Mediation Effect Analysis

	(1) GTFP	(2) TS	(3) GTFP
prod	0.0649***	0.7568***	0.0579***
	(0.0092)	(0.1058)	(0.0100)
TS			0.0093*
			(0.0054)
gov	-0.0001***	-0.0007***	-0.0001***
	(0.0000)	(0.0001)	(0.0000)
ent	-0.0063**	-0.1745***	-0.0047
	(0.0030)	(0.0343)	(0.0031)
fdi	-0.4915***	-0.3331	-0.4884***
	(0.0900)	(1.0412)	(0.0897)
env	0.0003	-0.0165	0.0004
	(0.0016)	(0.0185)	(0.0016)
_cons	0.9514***	0.7363***	0.9445***
	(0.0226)	(0.2618)	(0.0229)
N	300	300	300
adj. R^2	0.6782	0.7622	0.6807

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.3 Moderating Effects

Table 5reveals that the type of industrial agglomeration significantly alters the impact of new quality productive forces. Specifically, the agglomeration of high-tech industries and specialized productive services both strengthen the positive relationship with green total factor productivity, likely by concentrating resources and fostering focused knowledge spillovers. In contrast, diversified agglomeration attenuates this effect, suggesting that resource dispersion and weaker inter-firm linkages in such environments hinder the necessary innovative synergies.

Table 5 Moderating Effects

	(1)	(2)	(3)	(4)
prod	0.0649***	0.0271**	0.0429***	0.0123
	(0.0092)	(0.0122)	(0.0123)	(0.0094)
pro*high		0.0190***		
		(0.0043)		
pro*prof			0.0622**	
			(0.0279)	
pro*mul				-0.2987***
				(0.0322)
gov	-0.0001***	-0.0001***	-0.0001***	-0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ent	-0.0063**	-0.0001	-0.0018	-0.0007
	(0.0030)	(0.0032)	(0.0032)	(0.0026)
fdi	-0.4915***	-0.4890***	-0.4426***	-0.4992***
	(0.0900)	(0.0868)	(0.0911)	(0.0797)
env	0.0003	0.0015	-0.0008	0.0014
	(0.0016)	(0.0016)	(0.0016)	(0.0014)
high		-0.0150*		
		(0.0090)		
prof			0.1747***	
			(0.0597)	
mul				-0.1071**
				(0.0442)
_cons	0.9514***	0.9767***	0.9641***	1.0066***
	(0.0226)	(0.0227)	(0.0238)	(0.0220)
N	300	300	300	300
adj. R^2	0.6782	0.7011	0.6963	0.7678

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.4 Robustness Check

4.4.1 Substituting the Dependent Variable Measurement Model

Table 6 presents the results of a robustness analysis using three different models to calculate the dependent variable, GTFP. Column (1) replicates our baseline EBM-GML model. For comparison, Columns (2) and (3) utilize GTFP measures derived from the SBM and DDF models, respectively, following the methodologies of Qian Zhengming et al. (2013)[31] and Yue Li et al. (2017)[32].

It is evident that all three measurement methods yield regression results that pass the significance level test at 1%, indicating a strong robustness of the data results. This supports the conclusion that "the enhancement of new quality productive forces significantly promotes the growth of green total factor productivity," thus reinforcing the reliability of the findings.

ISSN 2616-5902 Vol. 7, Issue 7: 41-49, DOI: 10.25236/AJBM.2025.070706

Table 6 Substituting the Dependent Variable Measurement Model

	(1) EBM	(2) SBM	(3) DDF
prod	0.0649***	0.1113***	0.0340***
	(0.0092)	(0.0309)	(0.0112)
gov	-0.0001***	-0.0004***	-0.0000
	(0.0000)	(0.0000)	(0.0000)
ent	-0.0063**	0.0006	-0.0049
	(0.0030)	(0.0100)	(0.0036)
fdi	-0.4915***	-1.0449***	-0.3601***
	(0.0900)	(0.3041)	(0.1098)
env	0.0003	-0.0046	0.0030
	(0.0016)	(0.0054)	(0.0019)
_cons	0.9514***	0.9492***	0.9486***
	(0.0226)	(0.0765)	(0.0276)
N	300	300	300
adj. R^2	0.6782	0.6592	0.4745

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.4.2 Lag Effect Test

Table 7 reports the regression results with the explanatory variable lagged by one year and two years. The results show that the regressions with both one-year and two-year lags still pass the 1% significance level test, further reinforcing the robustness of the conclusion that "the enhancement of new quality productive forces significantly promotes the growth of green total factor productivity." This strengthens the reliability of the findings.

Table 7 Lag Effect Test

	(1)	(2)	(3)
prod	0.0649***		
	(0.0092)		
prod_1		0.0778***	
		(0.0107)	
prod_2			0.0833***
			(0.0125)
gov	-0.0001***	-0.0001***	-0.0001***
	(0.0000)	(0.0000)	(0.0000)
ent	-0.0063**	-0.0060*	-0.0030
	(0.0030)	(0.0033)	(0.0038)
fdi	-0.4915***	-0.5195***	-0.5137***
	(0.0900)	(0.0990)	(0.1088)
env	0.0003	0.0002	0.0010
	(0.0016)	(0.0018)	(0.0018)
_cons	0.9514***	0.9273***	0.8882***
	(0.0226)	(0.0272)	(0.0318)
N	300	270	240
adj. R^2	0.6782	0.6351	0.6283

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.4.3 Placebo Test

To ensure the robustness of our findings, a placebo test was conducted following the methodology of Feng Jin et al. (2023)[33]. The core explanatory variable was randomly assigned across observations, and the baseline regression was repeated 1,000 times. As illustrated in Figure 1 , the distribution of the resulting coefficients is approximately normal, with a mean centered at zero. This result is starkly different from our main finding, indicating that our results are not driven by unobserved random factors and successfully pass the placebo test.

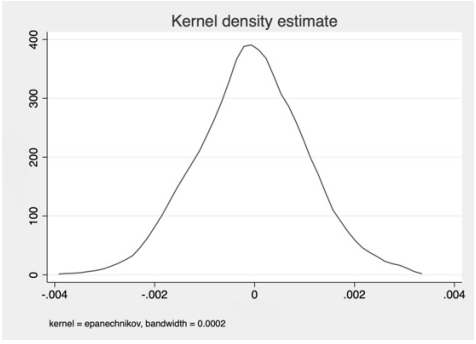

Figure 1 Placebo Test

ISSN 2616-5902 Vol. 7, Issue 7: 41-49, DOI: 10.25236/AJBM.2025.070706

4.5 Heterogeneity Test

The country was divided into eastern, central, and western regions for separate regression analyses. The regression results are shown in Table 8. The results indicate that new quality productive forces in the eastern region passes the 1% significance level test, while the central and western regions do not, revealing regional heterogeneity.

Table 8 Heterogeneity Test

	(1) Nationwide	(2) Eastern	(3) Central	(4) Western
prod	0.0649***	0.0769***	0.0159	0.0108
	(0.0092)	(0.0123)	(0.0202)	(0.0275)
gov	-0.0001***	-0.0001***	-0.0001**	-0.0005***
	(0.0000)	(0.0000)	(0.0000)	(0.0001)
ent	-0.0063**	-0.0173*	-0.0111***	0.0123**
	(0.0030)	(0.0092)	(0.0040)	(0.0060)
fdi	-0.4915***	-0.4530***	-0.1862	-0.6000
	(0.0900)	(0.1020)	(0.2817)	(0.4172)
env	0.0003	0.0006	-0.0019	0.0006
	(0.0016)	(0.0021)	(0.0022)	(0.0039)
_cons	0.9514***	0.9654***	1.0485***	0.9679***
	(0.0226)	(0.0599)	(0.0364)	(0.0424)
N	300	110	80	110
adj. R^2	0.6782	0.7900	0.8276	0.6077

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The observed regional heterogeneity is likely due to the eastern region's advanced economic ecosystem, which provides the necessary talent, technology, and environmental management capabilities for new quality productive forces to be effective. In contrast, the less developed central and western regions lack these preconditions, thus limiting the impact.

5. Conclusion and Policy Recommendations

5.1 Conclusion

This study, based on macro data from 30 provinces in Chinese mainland from 2010 to 2019, analyzes the impact of new quality productive forces on green total factor productivity (GTFP) and its underlying mechanisms. The main findings are as follows:

First, new quality productive forces significantly promote the improvement of GTFP at the national level, and this conclusion remains valid after multiple robustness tests.

Second, the mediation effect analysis shows that new quality productive forces enhance GTFP by driving the upgrading of the industrial structure toward more advanced forms.

Third, high-tech industry agglomeration and the specialized agglomeration of productive services effectively strengthen the positive impact of new quality productive forces on GTFP.

Finally, the effect of new quality productive forces on GTFP varies across regions, with significant growth observed in the eastern region, while no significant improvement is seen in the central and western regions.

5.2 Policy Recommendations

Based on the above conclusions, this paper proposes the following policy recommendations to promote the development of new quality productive forces and related industries, thereby enhancing GTFP:

A comprehensive policy framework should prioritize the development of high-tech industries and AI through strategic incentives while fostering specialized industrial clusters and the technological modernization of traditional sectors. To ensure inclusive, balanced growth, these efforts must be complemented by targeted infrastructure and policy support for central and western regions, facilitating technology transfer from the east. Concurrently, stringent environmental regulations are essential to drive the adoption of clean technologies, alongside increased investment in renewable energy. Foundational to this strategy is the cultivation of high-skilled human capital, which requires competitive incentives and robust collaboration between industry and academia to meet evolving industrial demands.

By implementing these integrated policies, policymakers can effectively cultivate new quality productive forces, thereby enhancing GTFP and steering the economy towards a high-quality, sustainable future.

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