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Research on the mechanisms and realization pathways through which new quality productive forces empower the development of Gansu's modern industrial system

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Abstract. To systematically investigate the mechanisms and realization pathways through which New Quality Productive Forces (NQPF) facilitate the development of Gansu's modern industrial system, this study employs balanced panel data for 12 prefecture-level cities in Gansu Province from 2012 to 2024. A hierarchical entropy-weighting method is adopted to quantify the levels of New Quality Productive forces (NQP) and Modern Industrial System (MIS) development. Two-way fixed-effects, mediation-effects, and interaction-effects models are subsequently constructed for empirical testing. The empirical results indicate that new quality productive forces significantly promote the development of Gansu's modern industrial system. Both digital technological innovation and green technological innovation serve as mediating mechanisms, with the latter exhibiting a more robust transmission effect. Moreover, digital and green technological innovations demonstrate a significant positive synergistic effect. Heterogeneity analysis reveals that the empowering effect is concentrated primarily in cities with higher levels of economic development, non-resource-based cities, and cities with a stronger secondary industrial base. In addition, a central-city spillover pattern is observed, while the release of policy effects exhibits a certain time lag.

Keywords: Gansu Province, new quality productive forces, modern industrial system, digital technological innovation, green technological innovation

1. Introduction

New quality productive forces represent an advanced form of productivity characterized by innovation as the primary driving force. They transcend traditional modes of economic growth and conventional paths of productivity development and embody the features of high technology, high efficiency, and high quality, in line with the new development philosophy. In January 2024, during the eleventh collective study session of the Political Bureau of the Central Committee of the Communist Party of China, President Xi Jinping emphasized: "They are generated through revolutionary technological breakthroughs, innovative allocation of production factors, and profound industrial transformation and upgrading. Their fundamental connotation lies in the qualitative enhancement and optimized combination of labor, means of production, and objects of labor, while a substantial increase in total factor productivity constitutes their core hallmark. Innovation is their defining characteristic, superior quality is the key, and advanced productivity is their essential nature" [1]. At present, Gansu Province is not only a traditional industrial base in western China but also bears the strategic responsibility of safeguarding the ecological environment of the Yellow River Basin. Against this backdrop, fostering the development of a modern industrial system through the cultivation of new quality productive forces carries considerable practical significance for the province.

In July 2024, the *Opinions of the Central Committee of the Communist Party of China and the State Council on Accelerating the Comprehensive Green Transformation of Economic and Social Development* proposed to "accelerate the coordinated transformation of digitalization and green development", "promote the deep integration of industrial digitalization, intelligence, and green development", and emphasized "harnessing digital technologies to empower the green transition" [2]. The strategy of coordinated digital and green development provides a clearer and more practical pathway through which new quality productive forces can facilitate the construction of a modern industrial system. For Gansu Province, a traditional industrial base in western China and a key ecological conservation area within the Yellow River Basin, the development of a modern industrial system is constrained by two critical factors: the imperative of maintaining the ecological protection baseline and the long-standing path dependence on resource-based development. In conjunction with the strategic initiatives advanced at the *Ninth Plenary Session of the Fourteenth Gansu Provincial Party Committee*—namely, the deepening of the "Strengthening Industry Initiative" and the implementation of the "Seven Bases, One Ecological Barrier, and One Strategic Corridor" development framework—the strategic orientation and principal challenges of Gansu's modern industrial system development have been more explicitly defined.

However, existing studies have largely focused on the general patterns through which new quality productive forces drive the development of modern industrial systems at the national level or in economically advanced regions. Comparatively little attention has been paid to less-developed, resource-dependent regions such as Gansu Province, which simultaneously face the dual tasks of transforming a traditional industrial base and constructing an ecological security barrier. Consequently, the empowering mechanisms and boundary conditions of new quality productive forces in such contexts remain insufficiently understood. Against this background, this study seeks to address three key research questions. First, under the dual constraints of ecological protection requirements and long-term resource dependence, can new quality productive forces effectively promote the development of Gansu's modern industrial system? Second, through what mechanisms do new quality productive forces facilitate the construction of Gansu's modern industrial system, and what respective roles do digital technological innovation and green technological innovation play in this process? Third, what patterns of spatial heterogeneity characterize this empowering effect across cities with different resource endowments and industrial foundations? To answer these questions, this study employs panel data for 12 prefecture-level cities in Gansu Province covering the period from 2012 to 2024. After evaluating the development levels of new quality productive forces and the modern industrial system, two-way fixed-effects, mediation-effects, and interaction-effects models are constructed to conduct empirical analyses. The findings are expected to provide both theoretical insights and empirical evidence for helping traditional industrial bases in western China, with Gansu as a representative case, overcome resource dependence and achieve a coordinated transition toward digitalization and green development.

2. Literature review and research hypotheses

2.1. New quality productive forces and the development of Gansu's modern industrial system

From the perspective of Gansu Province's development context, the construction of a modern industrial system is constrained by strong resource path dependence and long-standing structural rigidities. Lei Li [3] argues that Gansu's industrial sector has long suffered from a "structural disadvantage", whereby resources and production factors are disproportionately allocated to low-efficiency sectors, and the traditional growth model driven by scale expansion and resource inputs can no longer sustain industrial transformation and upgrading. Ruiyu Zhang further finds that the development level of the modern industrial system in the Gansu section of the Yellow River Basin remains relatively low and still lags considerably behind the national average [4]. Against this backdrop, the cultivation and enhancement of new quality productive forces provide new opportunities for Gansu to overcome resource dependence, optimize its industrial structure, and reshape its industrial competitiveness. The underlying mechanism lies in the continuous advancement of technological innovation and the transformation of production methods. On the one hand, new quality productive forces facilitate the upgrading and modernization of traditional industries; on the other hand, they promote the development of emerging industries, thereby supporting the overall construction of a modern industrial system. Empirical evidence from a study by Qian Zhang [5] based on the five northwestern provinces of China also demonstrates that new quality productive forces exert a significant positive effect on the development of modern industrial systems.

Based on the above analysis, the following hypothesis is proposed:

H1: New quality productive forces can significantly promote the development of Gansu's modern industrial system.

2.2. Mechanisms through which new quality productive forces empower the development of Gansu's modern industrial system

2.2.1. Digital technological innovation

Digital technological innovation is an important vehicle for the formation and realization of new quality productive forces and serves as a key mediating mechanism in promoting the transformation and upgrading of industrial systems. Digital technologies can improve industrial performance through multiple channels. Da Wei [6] argues that digital governance effectively stimulates regional innovation vitality, enhances the efficiency of factor allocation, and significantly empowers the development of modern industrial systems, with particularly pronounced effects in central and western China as well as inland regions. For Gansu, a typical traditional industrial base in western China, industrial transformation has long been constrained by inefficient information flows, inadequate production coordination, and delayed decision-making. Digital technological innovation can help alleviate these bottlenecks. Specifically, it facilitates the digital, networked, and intelligent transformation of traditional manufacturing industries. Through the application of industrial Internet technologies, intelligent manufacturing, and platform-based collaboration, digital innovation strengthens the resilience of industrial and supply chains while enhancing the operational efficiency and risk resistance of the industrial system [7]. Moreover, under the national strategy of the "East Data, West Computing" initiative, the development of the Gansu national computing hub and the Qingyang data center cluster has provided the province with a growing foundation in computing infrastructure and data factor aggregation. These developments offer practical support for digital technological innovation to drive industrial upgrading [8]. Based on the above analysis, the following hypothesis is proposed:

H2: New quality productive forces indirectly promote the development of Gansu's modern industrial system by fostering digital technological innovation.

2.2.2. Green technological innovation

Green technological innovation constitutes another important mechanism through which new quality productive forces influence the development of a modern industrial system. Green development is not only an intrinsic requirement for high-quality economic growth but also a fundamental value orientation for the construction of a modern industrial system. Hutao Yang [9] points out that a modern industrial system should possess distinct green characteristics and that only through the coordinated advancement of intelligentization, greening, and industrial integration can the longstanding dilemma of high energy consumption, high emissions, and low efficiency be effectively addressed. Based on research on urban agglomerations in the Yellow River Basin, Zhe Kang finds that technological innovation is one of the key determinants of industrial pollution reduction and carbon mitigation, highlighting the critical role of green technological progress in facilitating industrial transformation under ecological constraints [10]. For resource-based regions such as Gansu, which simultaneously function as resource extraction bases and ecologically significant areas within the Yellow River Basin, balancing pollution reduction, carbon mitigation, and industrial upgrading is particularly challenging. Green technological innovation not only helps alleviate the development lock-in associated with resource dependence but also promotes the transition from resource-driven to innovation-driven economic growth. Bin Zhai [11] argues that the scientific transformation of resource-based regions fundamentally depends on technological progress capable of correcting the traditional extensive development model. Based on the above analysis, the following hypothesis is proposed:

H3: New quality productive forces indirectly promote the development of Gansu's modern industrial system by fostering green technological innovation.

2.3. The positive interaction between green technological innovation and digital technological innovation

Building upon the foregoing discussion, it is also necessary to consider the potential synergistic relationship between digital technological innovation and green technological innovation. Haochang Yang [12] argues that the coordinated advancement of digital-intelligent transformation and green development has become a core driving force for overcoming resource and environmental constraints, as well as the problems of low quality and low efficiency in the manufacturing sector, thereby facilitating high-quality development. Accordingly, in the process through which new quality productive forces empower the development of Gansu's modern industrial system, digital and green technological innovations are unlikely to operate independently. Instead, they may reinforce one another and generate a synergistic effect, thereby further amplifying the empowering impact of new quality productive forces on the construction of Gansu's modern industrial system. Based on the above analysis, the following hypothesis is proposed:

H4: Digital technological innovation and green technological innovation exhibit a significant positive interaction effect in promoting the development of Gansu's modern industrial system.

3. Measurement of indicators and data sources

3.1. Measurement method and data sources

This study employs panel data for 12 prefecture-level cities in Gansu Province from 2012 to 2024 to construct a balanced city-year panel dataset. The empirical data are primarily collected from the *Gansu Statistical*

Yearbook (formerly the *Gansu Development Yearbook*), the *China City Statistical Yearbook*, the *China Urban Construction Statistical Yearbook*, annual statistical bulletins issued by the Gansu provincial government, the official website of the National Bureau of Statistics of China, the China Research Data Service Platform (CNRDS), and the EPS Data Platform. Missing observations for a small number of indicators in certain years are supplemented using interpolation methods.

A hierarchical entropy-weighting method is employed to quantify the levels of New Quality Productive forces (NQP) and the development of the Modern Industrial System (MIS). First, all raw data are normalized using the range standardization method according to the attributes of the indicators, with negative indicators being reverse-standardized. Second, within each first-level dimension, the information entropy, coefficient of variation, and corresponding weights of the second-level indicators are calculated to obtain composite scores for each dimension. Finally, using these dimensional scores as the basis, the entropy-weighting method is further applied to determine the weights of the first-level dimensions, which are then aggregated to construct the comprehensive NQP and MIS indices.

3.2. Construction of the evaluation index system for the development of the modern industrial system

The *Outline of the Fifteenth Five-Year Plan for National Economic and Social Development of the People's Republic of China* states that China should: "Maintain the focus of economic development on the real economy, adhere to the directions of intelligentization, green development, and integration, accelerate the building of a manufacturing powerhouse, a quality powerhouse, an aerospace powerhouse, a transportation powerhouse, and a cyber powerhouse, maintain a reasonable share of manufacturing in the economy, and establish a modern industrial system with advanced manufacturing as its backbone" [13]. Guided by these policy objectives and drawing upon existing domestic research, this study constructs an evaluation index system for the development of the modern industrial system with reference to the work of Muxi Lin, Lijuan Ji, and their collaborators [14, 15]. The specific indicators are presented in Table 1.

Table 1. Evaluation index system for the development of the modern industrial system

First-Level Dimension	Second-Level Indicator	Unit	Direction
Real Economy	Industrial value added	RMB 10,000	+
	Gross Domestic Product (GDP)	RMB 10,000	+
	Total value of imports and exports	RMB 10,000	+
	Urban road area per capita	m²	+
	Share of the primary industry	%	-
	Share of the secondary industry	%	+
	Share of the tertiary industry	%	+
Technological Innovation	R&D personnel	Persons	+
	Number of institutions engaged in R&D activities	Units	+
	R&D expenditure	RMB 10,000	+
	Proportion of enterprises applying for patents	%	+
	Proportion of enterprises filing invention patent applications	%	+

Table 1. Continued

Modern Finance	Digital Financial Inclusion Index	—	+
	Value added of the financial sector	RMB 10,000	+
	Average wage of employees in the financial sector	RMB	+
	Outstanding loan balance of financial institutions at year-end	RMB 10,000	+
	Employment in the financial sector	10,000 persons	+
Human Resources	Enrollment in higher education institutions	Persons	+
	Population aged 15–64	10,000 persons	+
	Resident population at year-end	10,000 persons	+
	Government expenditure on education	RMB 10,000	+
	Government expenditure on healthcare	RMB 10,000	+
	General public budget revenue	RMB 10,000	+
	Holdings of public libraries	10,000 volumes/items	+

3.3. Construction of the evaluation index system for new quality productive forces

This study draws upon the work of Jue Wang et al. [16] to construct the basic evaluation framework for new quality productive forces from the three fundamental dimensions of laborers, objects of labor, and means of labor. The specific selection of indicators is further informed by Qian Zhang's study of new quality productive forces in the five northwestern provinces of China [5]. Based on these references, an evaluation index system for the level of new quality productive forces is established, as shown in Table 2.

Table 2. Evaluation index system for new quality productive forces

First-Level Dimension	Second-Level Indicator	Unit	Direction
New-Quality Laborers	Average wage of employed workers	RMB	+
	Number of higher education institutions	Institutions	+
New-Quality Objects of Labor	Number of Internet users	10,000 households	+
	Total telecommunications business volume	RMB 10,000	+
	Volume of municipal solid waste collected and transported	10,000 tons	+
New-Quality Means of Labor	Number of artificial intelligence enterprises	Firms	+

4. Empirical analysis of the empowering effect of new quality productive forces on the modern industrial system

4.1. Variable selection and model specification

Dependent variable is as follows:

The dependent variable is the level of development of the Modern Industrial System (MIS). It is measured using the evaluation index system constructed in the previous section, with the comprehensive scores for the prefecture-level cities of Gansu Province calculated through the hierarchical entropy-weighting method.

Core Explanatory Variable: The core explanatory variable is the level of New Quality Productive forces (NQP). The corresponding scores are likewise derived from the evaluation index system established above and calculated using the hierarchical entropy-weighting method.

Mediating Variables: To further identify the mechanisms through which new quality productive forces influence the development of the modern industrial system, two mediating variables are introduced.

First, Digital technological innovation (DIG) is measured by the number of digital patent applications and is used to capture the level of digital innovation activity in each city.

Second, Green technological innovation (GRE) is measured by the number of green patent applications and reflects each city's capacity for green technology supply and its level of green innovation.

Control Variable: This study includes the level of Urbanization (Urban) as a control variable, measured by the urban population. Urbanization is closely associated with labor agglomeration, infrastructure development, and market expansion, all of which may influence both the development of new quality productive forces and the construction of a modern industrial system. Accordingly, it is incorporated into the empirical models.

Variables for Heterogeneity Analysis: Given the substantial differences among Gansu's cities in terms of development foundations, resource endowments, industrial structures, and policy environments, several grouping variables are introduced for heterogeneity analysis. City development level: Cities are classified into high- and low-development groups according to whether their per capita GDP is above or below the sample median. Resource endowment: Jinchang, Baiyin, Qingyang, Jiayuguan, Wuwei, and Zhangye are classified as resource-based cities, while the remaining cities are classified as non-resource-based cities. Industrial structure: Cities are divided into high-secondary-industry and low-secondary-industry groups according to the median share of the secondary industry. Policy period: The sample period is divided into pre-policy and post-policy stages, using 2020 as the cutoff year.

To examine the overall effect of new quality productive forces on the development of Gansu's modern industrial system, the following baseline regression model is specified (see Equation (1)):

$$MIS_{it} = \alpha_0 + \alpha_1 NQP_{it} + \alpha_2 Urban_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{1}$$

To further investigate the transmission mechanisms through which new quality productive forces affect the development of the modern industrial system, digital technological innovation and green technological innovation are separately introduced as mediating variables, leading to the following mediation models (see Equations (2) and (3)):

$$M_{it} = \beta_0 + \beta_1 NQP_{it} + \beta_2 Urban_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{2}$$

$$MIS_{it} = \gamma_0 + \gamma_1 NQP_{it} + \gamma_2 M_{it} + \gamma_3 Urban_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{3}$$

Furthermore, to examine whether digital and green technological innovations exhibit a positive interaction effect in promoting the development of Gansu's modern industrial system, the following interaction model is constructed (see Equation (4)):

$$\begin{gathered} MIS_{it} = \delta_0 + \delta_1 NQP_{it} + \delta_2 DIG_{it} + \delta_3 GRE_{it} + \\ \delta_4 (DIG_{it} \times GRE_{it}) + \mu_i + \lambda_t + \varepsilon_{it} \end{gathered} \tag{4}$$

In these equations, MIS_{it} denotes the level of development of the modern industrial system, NQP_{it} represents the level of new quality productive forces, and M_{it} denotes the mediating variable, which corresponds to either Digital technological innovation (DIG) or Green technological innovation (GRE) in different specifications. $Urban_{it}$ is the urbanization control variable, while $DIG_{it} \times GRE_{it}$ represents the interaction term between digital and green technological innovations. μ_i and λ_t denote city and year fixed effects, respectively, and ε_{it} is the stochastic error term. In the empirical estimation, Equation (4) is specified in logarithmic form.

If α_1 is significantly positive, new quality productive forces are considered to promote the development of the modern industrial system. If both β_1 and γ_2 are statistically significant and the coefficient γ_1 declines relative to the baseline coefficient α_1 after the mediating variable is introduced, a mediation effect is established. A positive and statistically significant δ_4 indicates a significant positive interaction effect between digital and green technological innovations. Descriptive statistics for the variables are reported in Table 3.

Table 3. Descriptive statistics of the variables

	Observations	Mean	Standard Deviation	Minimum	Maximum
MIS	156	0.1605402	0.1702165	0.047968	0.9256264
NQP	156	0.0920451	0.1493856	0.0041434	0.8811371
DIG	156	284.3718	660.448	2	3,949
GRE	156	67.08654	124.1765	0	770
Urban	156	93.92789	75.55906	21.88	380.7926

4.2. Baseline regression analysis

To examine the overall impact of new quality productive forces on the development of Gansu's modern industrial system, the baseline regression is estimated using Stata 18. The results are presented in Table 4.

Table 4. Baseline regression results

Variable	Coefficient	Robust Standard Error	*t*-value	Significance
NQP	0.7381	0.0491	15.03	***
Urban	0.0011	0.0003	3.68	***
Year fixed effects	Controlled	-	-	-
City fixed effects	Controlled	-	-	-
Observations *N*	156	-	-	-
Within R^2	0.9112	-	-	-

Note: $^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. The same significance criteria apply to subsequent tables unless otherwise specified.

As reported in Table 4, the estimated coefficient for New Quality Productive forces (NQP) is 0.7381, which is positive and statistically significant at the 1% level. Regarding the control variable, the coefficient for Urbanization (Urban) is 0.0011, which is likewise positive and significant at the 1% level. These findings indicate that the development of new quality productive forces significantly promotes the construction of Gansu's modern industrial system. The empirical evidence thus provides preliminary support for Hypothesis H1.

4.3. Mediation effect analysis

To further uncover the mechanisms through which new quality productive forces influence the development of the modern industrial system, this study examines digital technological innovation and green technological innovation as separate mediating variables. The regression results are reported in Table 5.

Table 5. Results of the mediation effect analysis

	(1)	(2)	(3)	(4)
	Digital Mediation Model (DIG)	MIS Model (Including DIG)	Green Mediation Model (GRE)	MIS Model (Including GRE)
NQP	5,512.1907***	0.3587***	741.4594***	0.5867***
	(453.4962)	(0.0532)	(117.3895)	(0.0472)
Urban	2.8499	0.0009***	0.7866	0.0010***
	(2.2632)	(0.0002)	(0.7436)	(0.0002)
DIG		0.0001***		
		(0.0000)		
GRE				0.0002***
				(0.0000)
Year fixed effects	Controlled	Controlled	Controlled	Controlled
City fixed effects	Controlled	Controlled	Controlled	Controlled
N	156	156	156	156
Within R^2	0.6796	0.9642	0.5146	0.9492

As shown in Table 5, Columns (1) and (2) present the mediation results for digital technological innovation, while Columns (3) and (4) report the corresponding results for green technological innovation.

For the digital innovation channel, the estimated coefficient of NQP on DIG is 5,512.1907, which is positive and statistically significant at the 1% level. After incorporating DIG into the regression model for the modern industrial system, the coefficient of DIG is 0.0001, remaining positive and significant at the 1% level. Meanwhile, the coefficient of NQP declines from 0.7381 in the baseline model to 0.3587, while retaining statistical significance at the 1% level. These findings indicate that digital technological innovation partially mediates the relationship between new quality productive forces and the development of Gansu's modern industrial system, providing empirical support for Hypothesis H2.

For the green innovation channel, the coefficient of NQP on GRE is 741.4594, which is likewise significant at the 1% level. After including GRE in the regression model, the coefficient of GRE is 0.0002, positive and significant at the 1% level, while the coefficient of NQP decreases from 0.7381 to 0.5867 but remains statistically significant at the 1% level. These results suggest that green technological innovation also serves as a partial mediating mechanism through which new quality productive forces promote the development of Gansu's modern industrial system, thereby supporting Hypothesis H3.

To further assess the statistical robustness of the mediation effects, a Bootstrap procedure with 1,000 replications is employed to estimate the 95% confidence intervals of the indirect effects. The results are reported in Table 6.

Table 6. Bootstrap test results for the mediation effects

	(1)	(2)
	MIS = NQP + DIG + Urban + FE	MIS = NQP + GRE + Urban + FE
_bs_1	0.3587	0.5867**
	[-0.0588, 0.7762]	[0.2352, 0.9382]
Observations *N*	156	156

Note: Bootstrap estimates are based on 1,000 replications.

As reported in Table 6, the estimated mediation effect for the digital technological innovation pathway is 0.3587. The Bootstrap confidence interval, [-0.0588, 0.7762], includes zero, indicating that the mediation effect is only marginally significant and lacks strong statistical robustness. By contrast, the estimated mediation effect for the green technological innovation pathway is 0.5867, with a 95% confidence interval of [0.2352, 0.9382], which excludes zero entirely and is statistically significant at the 1% level. This finding suggests that the mediating role of green technological innovation is considerably more robust than that of digital technological innovation.

4.4. Interaction effect between digital and green technological innovation

Table 7. Results of the interaction effect analysis

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline	+ Digital	+ Green	Dual Innovation	Interaction	Standardized Interaction
NQP	0.9641***	0.9638***	0.9636***	0.9646***	0.8094***	0.8094***
	(0.0592)	(0.0578)	(0.0546)	(0.0529)	(0.0318)	(0.0318)
ln_digital		-0.0007		0.0027	-0.0067	
		(0.0074)		(0.0084)	(0.0090)	
ln_green			-0.0045	-0.0059	-0.0434***	
			(0.0055)	(0.0054)	(0.0122)	
interact					0.0084***	
					(0.0026)	
std_digital						0.0285**
						(0.0102)
std_green						-0.0057
						(0.0058)
std_interact						0.0139***
						(0.0043)

Table 7. Continued

_cons	0.0718***	0.0750**	0.0872***	0.0791**	0.1195***	0.0732***
	(0.0054)	(0.0323)	(0.0178)	(0.0338)	(0.0324)	(0.0029)
Observations *N*	156	156	156	156	156	156
City fixed effects	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Year fixed effects	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Adjusted R^2	0.9877	0.9876	0.9877	0.9876	0.9912	0.9912

Note: The interaction models are estimated using logarithmically transformed and standardized variables.

To examine whether digital technological innovation and green technological innovation jointly generate a positive interaction effect in promoting the development of Gansu's modern industrial system, an interaction model is estimated. The regression results are presented in Table 7.

As shown in Columns (5) and (6) of Table 7, the estimated coefficients for the interaction terms, interact and std_interact, are 0.0084 and 0.0139, respectively, and both are statistically significant at the 1% level. These findings indicate that digital technological innovation and green technological innovation reinforce one another in promoting the development of Gansu's modern industrial system, thereby providing empirical support for Hypothesis H4.

Moreover, in interaction models, the coefficients of the constituent variables represent their marginal effects when the interacting variable is held at zero. In Column (5), the coefficient of ln_digital is –0.0067, which is statistically insignificant, whereas the coefficient of ln_green is –0.0434, which is significant at the 1% level. To further interpret the interaction effect, a marginal effect analysis is conducted. The original interaction model is specified as (see Equation (4)):

$$MIS_{it} = \delta_0 + \delta_1 NQP_{it} + \delta_2 DIG_{it} + \delta_3 GRE_{it} + \\ \delta_4 (DIG_{it} \times GRE_{it}) + \mu_i + \lambda_t + \varepsilon_{it} \tag{4}$$

In the empirical estimation, the variables are logarithmically transformed, yielding (see Equation (5)):

$$MIS_{it} = \delta_0 + \delta_1 NQP_{it} + \delta_2 lnDIG_{it} + \delta_3 lnGRE_{it} + \\ \delta_4 (lnDIG_{it} \times lnGRE_{it}) + \mu_i + \lambda_t + \varepsilon_{it} \tag{5}$$

where $lnDIG_{it} = ln(DigitalPatentApplications + 1)$,
and $lnGRE_{it} = ln(GreenPatentApplications + 1)$.

Taking the partial derivative of equation (5) yields (see equation (6)):

$$\frac{\partial MIS_{it}}{\partial lnGRE_{it}} = \delta_3 + \delta_4 \cdot lnDIG_{it} \tag{6}$$

Substituting the estimated coefficients from Column (5) yields (see equation (7)):

$$\frac{\partial MIS}{\partial lnGRE} = -0.0434 + 0.0084 \times lnDIG \tag{7}$$

The calculation indicates that the marginal effect of green technological innovation becomes positive only when $lnDIG \geq 5.17$, which corresponds to approximately 176 digital patent applications. In other words, green technological innovation begins to exert a positive effect on the modern industrial system only after digital innovation has reached a certain threshold, highlighting the complementary nature of digital and green innovation.

For the standardized interaction model reported in Column (6), the coefficients of the constituent variables represent marginal effects when the interacting variable is held at its sample mean. The coefficient of std_digital is 0.0285, significant at the 5% level, whereas the coefficient of std_green is –0.0057 and statistically insignificant. These results further suggest that digital technological innovation plays a comparatively stronger and more stable facilitating role when considered in conjunction with green technological innovation.

4.5. Heterogeneity analysis

Table 8. Results of the heterogeneity analysis

	1.1	1.2	2.1	2.2
	High Development	Low Development	Resource-based	Non-resource-based
NQP	0.5522***	-0.0579	0.0595	0.7932***
	-0.0623	-0.3787	-0.3378	-0.0374
urban	0.0019***	0.0005	0.0006	0.0012***
	-0.0003	-0.0007	-0.0007	-0.0002
_cons	-0.0716**	0.0356	0.0457	-0.0544**
	-0.0284	-0.046	-0.0349	-0.021
City fixed effects	Controlled	Controlled	Controlled	Controlled
Year fixed effects	Controlled	Controlled	Controlled	Controlled
Observations *N*	78	78	78	78
Within R^2	0.9385	0.8862	0.8543	0.9443

Table 8. Contined

	3.1	3.2	4.1	4.2
	High Secondary Industry	Low Secondary Industry	Post-policy	Pre-policy
NQP	0.7088***	-0.325	0.1283**	1.0798***
	-0.1019	-0.2465	-0.0447	-0.0643
Urban	0.0013*	0.0001	0.0017***	0.0001
	-0.0005	-0.0004	-0.0003	-0.0003
_cons	-0.0126	0.0603*	-0.0115	0.0525*
	-0.0491	-0.0262	-0.0291	-0.0283
City fixed effects	Controlled	Controlled	Controlled	Controlled
Year fixed effects	Controlled	Controlled	Controlled	Controlled
Observations *N*	78	78	60	96
Within R^2	0.923	0.9416	0.8223	0.8748

The preceding analysis demonstrates that new quality productive forces exert a significant positive effect on the development of Gansu's modern industrial system, while digital technological innovation and green technological innovation serve as important mediating and synergistic mechanisms. To further explore the heterogeneity of this empowering effect, this study conducts subgroup analyses from four perspectives: city development level, resource endowment, industrial structure, and policy period. Specifically, cities are divided into high- and low-development groups according to the median level of per capita GDP during the sample period. Resource endowment is classified by designating Jinchang, Baiyin, Qingyang, Jiayuguan, Wuwei, and Zhangye as resource-based cities, with the remaining cities categorized as non-resource-based. Industrial structure is differentiated according to the median share of the secondary industry across the sample period, while the policy period is divided into pre- and post-2020 stages, with 2020 marking the beginning of the *Fourteenth Five-Year Plan* period. The estimation results are presented in Table 8.

The results reported in Columns (1.1) and (1.2) indicate substantial heterogeneity across cities with different levels of economic development. In high-development cities, the estimated coefficient of NQP is 0.5522, which is positive and statistically significant at the 1% level. By contrast, in low-development cities, the coefficient is –0.0579 and fails to reach statistical significance. These findings suggest that the empowering effect of new quality productive forces is more pronounced in economically advanced cities. Columns (2.1) and (2.2) reveal heterogeneity with respect to resource endowment. For resource-based cities, the estimated coefficient of NQP is 0.0595, which is statistically insignificant. In contrast, for non-resource-based cities, the coefficient reaches 0.7932 and is significant at the 1% level, indicating that new quality productive forces are more effective in promoting the development of the modern industrial system in cities with lower dependence on natural resources. Columns (3.1) and (3.2) examine differences arising from industrial structure. In cities with a relatively large secondary industrial sector, the coefficient of NQP is 0.7088 and significant at the 1% level. Conversely, in cities with a relatively small secondary industrial base, the coefficient is –0.3250 and statistically insignificant. This finding suggests that a stronger industrial foundation provides more favorable conditions for the productive transformation of technological and innovation resources. Finally, Columns (4.1) and (4.2) compare the policy periods before and after 2020. During the post-policy period, the estimated coefficient of NQP is 0.1283, significant at the 5% level, whereas during the pre-policy period the coefficient is 1.0798, significant at the 1% level. The relatively smaller coefficient observed after 2020 suggests that the benefits of policy implementation may require time to materialize fully, indicating the existence of a certain lag in the release of policy effects. Overall, the heterogeneity analysis indicates that the empowering effect of new quality productive forces is concentrated primarily in economically developed cities, non-resource-based cities, and cities with a stronger secondary industrial base. Moreover, the policy environment appears to influence the magnitude of this effect, with evidence of delayed policy transmission.

4.6. Robustness tests

To further ensure the reliability of the baseline regression results, three robustness checks are conducted. First, the contemporaneous measure of new quality productive forces is replaced with its one-period lagged value. Second, observations for the years 2020 and 2021 are excluded to eliminate the potential influence of the COVID-19 pandemic and other extraordinary circumstances during this period. Third, the sample for Lanzhou, the provincial capital, is excluded to assess whether the baseline findings are driven by an extreme-value city. The estimation results are reported in Table 9.

Table 9. Results of the robustness tests

	(1)	(2)	(3)	(4)
	Baseline	Lagged NQP	Excluding 2020–2021	Excluding Lanzhou
NQP	0.7381***		0.7947***	0.1786
	(0.0491)		(0.0538)	(0.2095)
Urban	0.0011***	0.0009***	0.0007***	0.0005*
	(0.0003)	(0.0002)	(0.0002)	(0.0003)
L.NQP		0.9120***		
		(0.0996)		
_cons	-0.0152	0.0027	0.0150	0.0424**
	(0.0283)	(0.0173)	(0.0205)	(0.0139)
Observations *N*	156	144	132	143
Within R^2	0.9112	0.9219	0.9202	0.8899

Columns (2), (3), and (4) of Table 9 report the results of the three robustness tests described above. The regression using the one-period lagged value of new quality productive forces yields a coefficient of 0.9120, which remains positive and statistically significant at the 1% level. Similarly, after excluding the observations for 2020 and 2021, the estimated coefficient of NQP is 0.7947, also positive and significant at the 1% level. These findings indicate that the positive relationship between new quality productive forces and the development of Gansu's modern industrial system is robust to alternative model specifications and sample adjustments. However, when the Lanzhou observations are excluded, the estimated coefficient of NQP declines substantially to 0.1786 and loses statistical significance. This result suggests that Lanzhou, as the provincial capital and the leading economic and innovation center of Gansu, plays a particularly important role in the process through which new quality productive forces promote the development of the province's modern industrial system. The baseline findings may therefore be partly driven by the strong demonstration and spillover effects associated with this core city.

5. Conclusion and policy implication

This study employs panel data for 12 prefecture-level cities in Gansu Province covering the period from 2012 to 2024 as the empirical sample. Comprehensive evaluation frameworks are constructed to measure both the level of Modern Industrial System development (MIS) and the level of New Quality Productive forces (NQP). On this basis, two-way fixed-effects, mediation-effects, and interaction-effects models, together with a series of heterogeneity analyses, are employed to investigate the overall impact of new quality productive forces on the development of Gansu's modern industrial system, the underlying transmission mechanisms, and regional variations in their effects. The empirical findings can be summarized as follows. First, new quality productive forces significantly promote the development of Gansu's modern industrial system. Second, both digital technological innovation and green technological innovation serve as important mediating channels through which new quality productive forces influence the development of the modern industrial system. However, the

Bootstrap analysis indicates that the mediating role of green technological innovation is statistically more robust than that of digital technological innovation. Third, digital technological innovation and green technological innovation exhibit a significant positive interaction effect, suggesting that the two forms of innovation reinforce one another in supporting industrial modernization. Fourth, digital technological innovation constitutes an important prerequisite for the effective functioning of green technological innovation. Green technological innovation generates positive effects only after digital technological innovation has reached a certain threshold. When digital innovation remains below its average level, the contribution of green innovation to the development of the modern industrial system is not fully realized. Fifth, the empowering effect of new quality productive forces exhibits substantial heterogeneity across regions. The subgroup regression results indicate that the positive impact is more pronounced in economically developed cities, non-resource-based cities, and cities with a relatively strong secondary industrial sector. Although positive effects are observed both before and after the implementation of relevant policy initiatives, the full benefits of these policies appear to be released only gradually, indicating the presence of a policy lag.

Based on these findings, the following policy recommendations are proposed.

First, promote the integrated development of digitalization and green transformation through a dual-engine strategy to advance the construction of the modern industrial system. As a traditional industrial base in western China and an ecologically sensitive region within the Yellow River Basin, Gansu faces the dual constraints of ecological protection requirements and long-standing resource dependence in developing its modern industrial system. Continuous efforts should therefore be devoted to fostering the integrated development of digitalization and green transformation. The interaction analysis demonstrates that, under the extreme assumption of an absence of green technological innovation, digital technological innovation alone has only a limited and statistically insignificant effect. Conversely, in the absence of digital technological innovation, green technological innovation may even exert a negative influence on the overall level of modern industrial system development. At average levels of development, digital technological innovation is already capable of generating positive outcomes, whereas green technological innovation requires a higher degree of digitalization to realize its full potential. Accordingly, digital technologies should be utilized to enhance industrial operations and production efficiency, while green technologies should guide improvements in industrial quality and structural upgrading. Coordinated and simultaneous progress in both dimensions can create mutually reinforcing effects and prevent the diminished returns or unintended setbacks associated with pursuing either strategy in isolation.

Second, strengthen the radiating role of central cities and enhance regional absorptive capacity. The heterogeneity and robustness analyses suggest that the empowering effects of new quality productive forces are concentrated primarily in cities with relatively strong economic and industrial foundations and depend to a considerable extent on Lanzhou as the provincial core city. By contrast, less-developed cities fail to exhibit significant empowering effects, revealing a clear pattern of dependence on the central city. This finding indicates that Gansu's innovation and technology commercialization capacities remain highly concentrated in Lanzhou. Reducing this spatial imbalance requires facilitating the cross-regional mobility of technological resources, skilled labor, computing capacity, and other strategic production factors. Through interregional cooperation, technology diffusion, and the sharing of infrastructure resources, the absorptive capacity of other prefecture-level cities can be strengthened. The province should gradually shift from a development model characterized by isolated growth poles to one based on coordinated regional networks. In this framework, central cities should serve as hubs for integrating resources, concentrating production factors, and disseminating innovation capabilities, while other cities develop industrial platforms capable of absorbing, adapting, and transforming these resources in accordance with their own comparative advantages.

Third, implement differentiated industrial policies to release the benefits of new quality productive forces according to local conditions. Considerable differences exist among Gansu's cities in terms of resource endowments, industrial structures, and levels of economic development. The heterogeneity analysis confirms that the empowering effects of new quality productive forces are unevenly distributed rather than uniformly realized across regions. Accordingly, industrial policies should be tailored to local conditions, allowing different cities to identify their own development priorities. Regions with relatively strong economic and industrial foundations are better positioned to realize the benefits of new quality productive forces in the short term, whereas less-developed areas should prioritize strengthening their development capabilities and advancing transformation at an appropriate pace. Resource-based cities, in particular, should focus on utilizing new quality productive forces to overcome path dependence, improve the quality of industrial value chains, and facilitate industrial upgrading. By adopting differentiated development strategies and promoting the efficient allocation of innovation resources, Gansu can more effectively harness the dividends of new quality productive forces and accelerate the transformation and upgrading of its modern industrial system.

References

[1] Xinhua News Agency. (2024, February 1). Xi Jinping emphasized at the 11th collective study session of the Political Bureau of the CPC Central Committee: Accelerating the development of new quality productive forces and firmly advancing high-quality development. Central People's Government of the People's Republic of China. https: //www.gov.cn/yaowen/liebiao/202402/content_6929446.htm

[2] Xinhua News Agency. (2024, August 11). Opinions of the CPC Central Committee and the State Council on accelerating the comprehensive green transformation of economic and social development. Central People's Government of the People's Republic of China. https: //www.gov.cn/zhengce/202408/content_6967663.htm

[3] Li, L., Wang, J. G., & Wang, P. A. (2016). Factor effects of industrial structure change and industrial transformation and upgrading in Gansu Province [in Chinese]. *Arid Land Geography, 39(3*), 671–677.

[4] Zhang, R. Y., & Zhai, X. Y. (2025). Research on the development status of the modern industrial system in the Gansu section of the Yellow River Basin [in Chinese]. *Development, 8,* 61–64.

[5] Zhang, Q. (2026). An empirical study on new quality productive forces empowering the construction of modern industrial systems in Northwest China [in Chinese]. *Resource Development & Market, 42*(4), 563–571.

[6] Wei, D., Li, Y. X., & Sun, X. H. (2026). The enabling effect and coordination mechanism of government digital governance on modern industrial systems [in Chinese]. *Modern Finance and Economics (Journal of Tianjin University of Finance and Economics), 46*(2), 3–22.

[7] Zhou, W., & Bai, J. (2025). The mechanism, key directions, and strategic pathways of new quality productive forces promoting modern industrial system construction [in Chinese]. *Qilu Journal, 6,* 101–114.

[8] Wang, H. C., Liu, B. X., Chou, Y. F., Wang, J. B., Wei, X. H., & Liu, Q. J. (2023). The "East Data West Computing" Gansu hub Qingyang cluster: Current situation and prospects [in Chinese]. *Big Data, 9*(5), 111–133.

[9] Yang, H. T., & Mei, Z. (2026). Intelligence, greening, and integration in the construction of modern industrial systems [in Chinese]. *Journal of Chongqing Technology and Business University (Social Sciences Edition), 43*(1), 1–13.

[10] Kang, Z., Li, W., & Liu, W. (2023). Factors influencing industrial pollution reduction and carbon mitigation in urban agglomerations of the Yellow River Basin and policy strategies [in Chinese]. *China Environmental Science, 43*(4), 1946–1956.

[11] Zhai, B., & Yang, X. F. (2010). Research on scientific transformation of resource-based cities in western China from the perspective of Scientific Outlook on Development: A case study of Gansu Province [in Chinese]. *Contemporary Economic Management, 32*(8), 60–64.

[12] Yang, H. C., Guo, X. L., Li, L. S., Liu, J., & Cheng, Z. H. (in press). *Synergistic empowerment of digital-intelligent and green transformation for high-quality manufacturing development: Mechanisms and effects* [in Chinese]. Studies in Science of Science. Advance online publication. https: //doi.org/10.16192/j.cnki.1003-2053.20260520.003

[13] Xinhua News Agency. (2026, March 13). *Outline of the 15th Five-Year Plan for national economic and social development of the People's Republic of China.* Central People's Government of the People's Republic of China. https: //www.gov.cn/yaowen/liebiao/202603/content_7062633.htm

[14] Lin, M. X., & Wang, C. (2022). Measurement and regional disparity of modern industrial system construction level [in Chinese]. *Economic Perspectives, 12,* 23–36.

[15] Ji, L. J. (2023). Measurement of China's modern industrial system construction level [in Chinese]. *Technology Economics and Management Research, 11,* 100–105.

[16] Wang, J., & Wang, R. J. (2024). New quality productive forces: Indicator construction and spatiotemporal evolution [in Chinese]. *Journal of Xi'an University of Finance and Economics, 37*(1), 31–47.