Global NEST Journal, **28** (6), 08574
Available online: 27/06/2026

From Innovation to Ecology: The Role of New Quality Productivity in Advancing Ecological Product Supply Efficiency

Jingbo Shao[1] and Xue Lei[2,*]

[1]International Tourism Culture College, Guizhou Normal University, Guiyang 550025, China
[2]School of Management, Shanghai University, Shanghai 200444, China

*Correspondence e-mail: leixue_work@shu.edu.cn

Abstract

Ecological product supply efficiency (SEEP) is critical to regional ecological quality and sustainable development, yet how new quality productivity (NQP) shapes this process remains underexplored. Using panel data from 30 provincial-level regions in China over 2011–2022, this study evaluates NQP development and SEEP through entropy-weighted TOPSIS and the super-SBM model, then applies a spatial econometric framework to examine their relationship. The results show that NQP significantly improves SEEP, and this effect extends beyond local boundaries, as regions with stronger NQP development also tend to lift supply efficiency in neighboring areas. Further analysis reveals that NQP works through several interconnected channels. It reshapes the workforce toward higher-skilled labor and pushes industries toward greener and more sophisticated structures, reducing pollution pressure while enriching ecological product supply. It also expands local government fiscal capacity, enabling greater investment in ecological protection, and raises enterprise profitability, motivating firms to participate more actively in ecological product supply. The strength of these effects varies by region, with the western region tending to gain more from NQP advancement than the more mature eastern region. These findings offer practical guidance for China and other developing economies seeking to improve ecological product supply through productivity-driven and regionally tailored policies.

Keywords: New Quality Productivity, Ecological Product Supply Efficiency, Spatial Spillover Effects, Industrial Structure Upgrading, Human Capital.

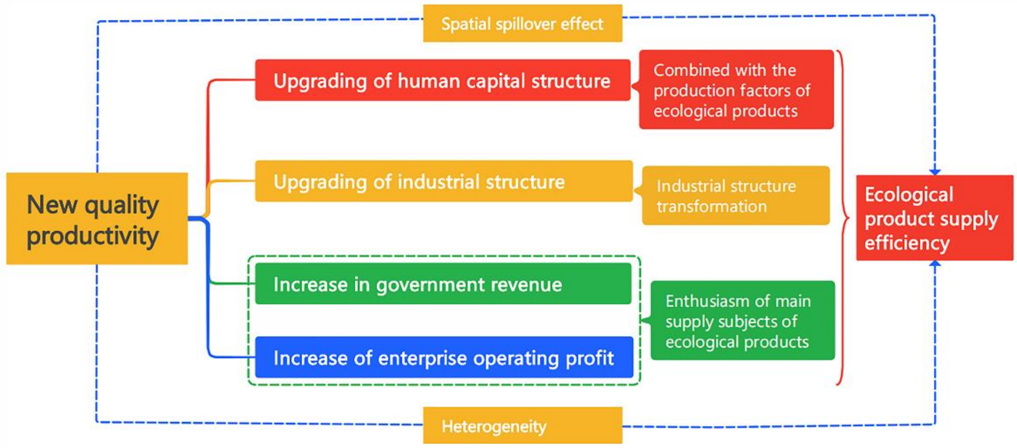
OPEN ACCESS

Received: 12/04/2026,

Accepted: 26/06/2026,

Available online: 27/06/2026

Graphical abstract



1. Introduction

Ecological products (EPR) mirror regional ecological conditions. Rampant human activities have triggered environmental degradation, while growing public demand for sound ecological surroundings has resulted in insufficient EPR supply (Zhang *et al.*, 2024a; Zhang *et al.*, 2024c), making it imperative to improve EPR supply capacity and efficiency (SEEP). As an emerging driver of high-quality economic development, new quality productivity (NQP) provides a new perspective for advancing ecological civilization and sustainable EPR development (Zhou and Richardson-Barlow, 2026). Defined in China's 2010 National Main Functional Area Plan, EPR corresponds to international ecosystem service research. Existing literature on SEEP mainly concentrates on quantitative evaluation, regional and categorical differences, and influencing factor identification.

Firstly, in the quantitative evaluation of supply effectiveness, the diversity of research approaches and assessment indicator frameworks has become a significant feature. Scholars generally tend to use data envelopment analysis (DEA) as an evaluation tool (Huang and Yao, 2021; Wang and Wang, 2020; Yang *et al.*, 2022), and on this basis, the traditional DEA model has been optimized, such as the introduction of a more refined Slacks-Based Measure (SBM) model to measure supply efficiency more accurately (He *et al.*, 2022b; Sheng, 2023; Tone, 2001). At the same time, when constructing the evaluation index system, more attention is paid to reality, and the consideration of undesirable outputs is included, which makes the evaluation results more comprehensive and accurate(Sheng, 2023). Secondly, the research perspective is extended to the analysis of the supply effectiveness of different regions or particular categories of EPR. Regional studies cover coastal areas such as the Yangtze River Drainage Area (Du and Guo, 2023), the Northeast Region of China (Yin and Wu, 2021), and Zhoushan, Zhejiang(He *et al.*, 2022a; He *et al.*, 2022b); at the level of specific EPR types, marine EPR (He *et al.*, 2022a), rural EPR (Huang and Yao, 2021), water EPR (He *et al.*, 2022b), and forest EPR (Yin and Wu, 2021) have become research hotspots. These studies offer a scientific foundation to support the meticulous execution of policies and optimization of resource allocation. Finally, regarding the examination of the determinants of supply efficiency, scholars have conducted in-depth discussions from multiple dimensions such as supply model innovation, management strategy optimization, Economic advancement tier, scientific and technological advancement, and industrial configuration transformation. Among them, efficient collaboration is regarded as the key to improving efficiency (Ma *et al.*, 2025; Xu *et al.*, 2025a), such as the PPP model (Zhang and Zhang, 2023), multi-agent collaborative governance, etc. (Huang *et al.*, 2022). The administration focuses on the equilibrium between input and output concerning EPR and the impact of climate change when making decisions (Xu *et al.*, 2024b; Zhong *et al.*, 2025). At the same time, economic changes, scientific and technological progress, and industrial restructuring cannot be ignored. Some scholars have studied these factors and advocated the transition of the economic development paradigm and the innovation of governance concept (Shen *et al.*, 2024; Wei *et al.*, 2024). In addition, several cutting-edge research studies have delved into the beneficial influence of the cyber-economic system on the value realization and SEEP, suggesting that the digital economy is capable of facilitating green transition and improving economic efficiency (Bai *et al.*, 2023; Zhang and Wang, 2023).

Existing studies on EPR supply efficiency largely focus on specific regions or EPR types, lacking a systematic, macro-level analysis of overall SEEP. Moreover, while prior work has identified determinants from supply approaches, management tactics, and industrial structures, most remain at the theoretical level without deep empirical mechanism exploration. In particular, how NQP affects SEEP remains largely unexamined, limiting the translation of theory into practice. To address these gaps, this study: (1) constructs a comprehensive analytical framework covering overall SEEP rather than fragmented sub-areas; and (2) empirically investigates the NQP→SEEP mechanism, providing both empirical evidence and theoretical support for EPR supply model innovation.

2. Theoretical framework and research conjecture

According to the externality theory (Ciccone and Peri, 2006; Dolbear, 1967), the technological innovation embedded in NQP generates positive externalities, thereby reducing the marginal cost of EPR supply. The Porter hypothesis (Ambec and Barla, 2006; Wang *et al.*, 2019) further predicts that innovation-driven development can achieve a "win-win" outcome between economic output and environmental protection. Specifically, the digital technologies embedded in NQP enable precise acquisition of production information (Liu and He, 2024; Zhou, 2026), optimization of resource allocation (Xu *et al.*, 2024a), and reduction of production costs (Zhou *et al.*, 2025), all of which contribute to enhancing the SEEP. Based on the above theoretical arguments, it is expected that the coefficient of the core explanatory variable in the baseline regression model is positive.

In the process of economic development, the input of ecological resources exerts a significant impact on economic growth in ecologically resource-endowed regions (Yue *et al.*, 2024). The Cobb-Douglas function (Zellner *et al.*, 1966), as a widely used production function model, can quantify the contribution of different factors to output. In essence, it serves as a technical recipe for transforming labor, capital, and resources into goods or services. Following existing studies (Wang *et al.*, 2021), assuming that the total output of EPR in region i at time t is denoted by Y_{it}, the EPR production function is constructed as Equation (1).

$$Y_{it} = A_{it} \times F\left(K_{it}, N_{it}, E_{it}, L_{it}\right) \tag{1}$$

where A_{it} denotes total factor productivity (TFP), representing the level of technology; K_{it} represents physical capital input (e.g., fixed assets of agriculture, forestry, animal husbandry, and fishery); N_{it} denotes land input (e.g., arable land, forest land, and grassland); E_{it} represents energy input; and L_{it} denotes labor input. The production function indicates that the output of EPR is determined by two components: "technological level" and "factor input". According to the externality theory (Ciccone and Peri, 2006) and the Porter hypothesis (Ambec and Barla, 2006), NQP generates positive externalities through technological innovation, thereby enhancing total factor productivity. Accordingly, Equation (2) is specified as follows:

$$A_{it} = A_0 \times e^{\gamma \cdot (NQP)_{it}} \tag{2}$$

where A_0 denotes the baseline technology level (a constant), γ represents the technology spillover intensity of NQP, with γ>0; and NQP denotes the comprehensive index of NQP. Equation (2) indicates that a higher NQP corresponds to a higher technology level A, following an exponential growth relationship. That is, technological innovation exhibits a cumulative effect. Substituting Equation (2) into Equation (1) yields Equation (3) as follows:

$$Y_{it} = A_0 \times e^{\gamma \cdot (NQP)_{it}} \times F\left(K_{it}, N_{it}, E_{it}, L_{it}\right) \tag{3}$$

The SEEP is defined as the ratio of output to total input, as specified in Equation (4).

$$\begin{aligned}(Eff)_{it} &= Y_{it} / \left(K_{it}+N_{it}+E_{it}+L_{it}\right) = \\ &\left(A_0 \times e^{\gamma \cdot (NQP)_{it}} \times F(.)\right) / \left(K_{it}+N_{it}+E_{it}+L_{it}\right)\end{aligned} \tag{4}$$

Based on Equation (4), taking the partial derivative of $(Eff)_{it}$ with respect to $(NQP)_{it}$ yields Equation (5).

$$\begin{aligned}\partial Y_{it} / \partial\left(NQP\right)_{it} &= \left(A_0 \times \gamma \times e^{\gamma \cdot (NQP)_{it}} \times F(.)\right) \\ &/ \left(K_{it}+N_{it}+E_{it}+L_{it}\right)\end{aligned} \tag{5}$$

where A_0>0, indicating that the baseline technology is positive; γ denotes the technology spillover intensity, which is theoretically assumed to be positive; $e^{\gamma \cdot (NQP)_{it}}$ is always positive; the output of the production function is also positive; and the denominator, representing factor inputs, is likewise positive. It follows that $\partial Y_{it}/\partial(NQP)_{it}$ >0 always holds. Accordingly, it is inferred that the coefficient of NQP in the empirical regression should be positive. Based on this, Hypothesis 1 is proposed as follows.

Hypothesis 1: NQP can advance the SEEP.

Hypothesis 1: NQP can advance the SEEP.

According to the new economic geography (Behrens and Thisse, 2007; Ottaviano, 2003; Ottaviano and Thisse, 2005), knowledge and technology exhibit spatial diffusion characteristics. NQP, through digital platforms, transcends geographical boundaries, generating knowledge spillovers and demonstration effects that drive efficiency improvements in neighboring regions (Li and Li, 2024). Specifically, digital technologies enable practitioners across different regions to share experiences and discuss technical challenges in real time (Jin *et al.*, 2024), allowing advanced technologies to diffuse rapidly to surrounding areas through market competition and labor mobility (Jin *et al.*, 2024), thereby forming a technology diffusion effect. Furthermore, NQP serves as a bridge for inter-regional cooperation, fostering regional EPR supply networks (Yan *et al.*, 2024), while policy synergies further amplify the spillover effects (Gao, 2023; Zhu *et al.*, 2024). Based on the above theoretical arguments, it is expected that the spatial spillover coefficient in the spatial Durbin model is positive.

Hypothesis 2: NQP exerts a spatial diffusion influence on the enhancement of SEEP.

According to new structural economics (Lin, 2011; Xu, 2026), economic development is accompanied by upgrading in human capital structure. NQP increases the proportion of advanced human capital while reducing that of primary human capital (Wang and Huang, 2024; Wu and Yang, 2022; Zhang and Lian, 2023), driving factor allocation toward optimality. This, in turn, enhances the productive capacity of human labor in protecting, restoring, and constructing ecosystems (Guaita Martínez *et al.*, 2022), thereby improving supply efficiency. Based on the above theoretical arguments, it is expected that the corresponding mediation effect coefficient of human capital upgrading in the mediation effect model is positive.

Hypothesis 3a: NQP enhances the SEEP through facilitating the advancement of the human capital configuration.

According to the Petty-Clark law (Xiao *et al.*, 2022), the technological and model innovations driven by NQP accelerate the transformation and upgrading of traditional industries, while simultaneously fostering emerging industries such as green energy and environmental protection technologies (Liu and He, 2024; Lu *et al.*, 2024; Zhang, 2024). This optimizes resource allocation and enhances the supply capacity of EPR (Zhou and Wang, 2022). Based on the above theoretical arguments, it is expected that the corresponding mediation effect coefficient of industrial structure upgrading in the mediation effect model is positive.

Hypothesis 3b: The improvement of NQP accelerates the SEEP by facilitating the advancement of the industrial structure.

According to fiscal federalism (Oates, 1999), NQP promotes economic growth, broadens the tax base, and increases government fiscal revenue, thereby enabling governments to allocate more resources to ecological conservation and green infrastructure development (Fang *et al.*, 2023; Liu *et al.*, 2025; Xu *et al.*, 2024a; Xu *et al.*, 2023). Based on the above theoretical arguments, it is expected that the corresponding mediation effect coefficient of government fiscal revenue in the mediation effect model constructed below is positive.

According to the profit maximization hypothesis (Williamson, 1966), NQP reduces production costs and improves product quality, thereby increasing corporate profits and incentivizing firms to expand the supply of EPR (Wang *et al.*, 2025; Yue *et al.*, 2024). Meanwhile, NQP facilitates the integration of upstream and downstream industrial chains (Liu and He, 2024), fostering a more tightly knit industrial ecosystem that drives green development across industries (Xu *et al.*, 2025b; Xu *et al.*, 2024a). Based on the above theoretical arguments, it is expected that both the coefficient of NQP on corporate operating profit and the coefficient of corporate operating profit on SEEP in the mediation effect model are positive.

Hypothesis 3d: NQP enhances the SEEP by increasing the operating profit of enterprises.

According to the new economic geography (Ottaviano and Thisse, 2005)(Krugman, 1991), regions differ in natural resource endowments, economic development levels, and institutional environments, leading to heterogeneous effects of NQP application (Li and Li, 2024). In regions rich in natural resources and with higher levels of economic development (Lu *et al.*, 2024; Zhu *et al.*, 2024), NQP can be more effectively translated into EPR supply capacity, whereas in resource-scarce and economically underdeveloped regions, the potential of NQP is constrained (Jia *et al.*, 2024). Based on the above theoretical arguments, it is expected that the coefficient of the interaction term in the moderation effect model is not equal to zero.

Hypothesis 4: There is heterogeneity in the geographical attributes of NQP to the SEEP.

To provide a holistic view of the research logic discussed above, **Figure 1** illustrates the overall theoretical framework.

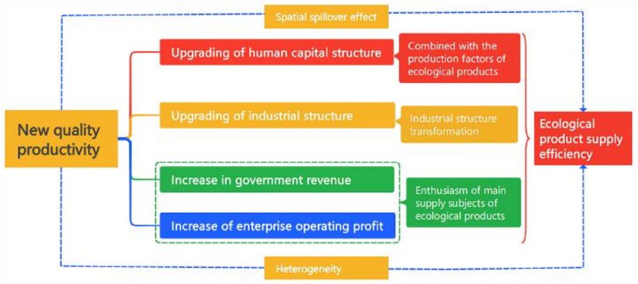


Figure 1. Theoretical mechanism diagram of NQP affecting the SEEP.

Figure 2. Map of China (Approval Number: GS (2019) 1680), containing the Nine-Dash Line in the South China Sea and Taiwan Province as an inalienable part of China's territory. Data source: Standard Map Service of the Ministry of Natural Resources (http://bzdt.ch.mnr.gov.cn/). The map has not been modified in any way.

3. Research design

3.1. *Overview of the study area: China*

This study covers 30 mainland Chinese provinces (excluding Hong Kong, Macao, Taiwan, and Tibet), spanning diverse geographical zones—from the eastern seaboard to the western plateau and from northern cold regions to southern tropical areas—with significant regional economic disparities: the east is economically developed, the central region is rising, and the west is resource-rich with high development potential. The research area is illustrated in **Figure 2**.

3.2. *Data sources*

Since the EPR policy was launched in 2010, this study uses panel data from 30 provincial-level administrative regions (excluding Hong Kong, Macao, Taiwan, and Tibet) covering the period 2011–2022. The data are sourced from various national and provincial statistical yearbooks and bulletins, including the China Statistical Yearbook and China Ecological Environment Bulletin, etc. Missing values are imputed using the average growth rate of the previous five years. The data details are shown in **Table 1**.

Table 1. Data Sources and Variable Description.

Variable	Time Span	Spatial Resolution	Data Source	URL/Access
SEEP (Dependent)	2011–2023	Provincial	China Statistical Yearbook; China Energy Statistical Yearbook; China Tourism Statistics Yearbook; Ecological Environment Bulletin; EPS Database	http://www.stats.gov.cn; Various provincial yearbooks; https://vpn.gufe.edu.cn/https/77726476706e69737468656265737421fffb408c69357843700d9de29b5a2e7bdc1e/#/datas_home?cubeId=1320
NQP (Independent)	2011–2023	Provincial	China Statistical Yearbook; China Science and Technology Statistical Yearbook; EPS Database	http://www.stats.gov.cn; https://vpn.gufe.edu.cn/https/77726476706e69737468656265737421fffb408c69357843700d9de29b5a2e7bdc1e/#/datas_home?cubeId=1320
Control Variables; Mechanism variables	2011–2023	Provincial	China Energy Statistical Yearbook; China Population and Employment Statistical Yearbook; EPS Database	Various provincial yearbooks; https://vpn.gufe.edu.cn/https/77726476706e69737468656265737421fffb408c69357843700d9de29b5a2e7bdc1e/#/datas_home?cubeId=1320

(1) Objective function:

$$\theta = min\frac{1+\frac{1}{m}\sum_{e=1}^{m}\frac{s_e^{-}}{x_{eo}}}{1-\frac{1}{q+h}\left(\sum_{f=1}^{q}\frac{s_f^{+}}{y_{fo}}+\sum_{g=1}^{h}\frac{s_g^{-}}{b_{go}}\right)} \tag{6}$$

(2) Constraint conditions:

$$\begin{aligned} & x_{eo} \geq \sum_{j=1,j\neq o}^{n}\omega_j x_{ij} - s_i^{-} \qquad i=1,2,3\ldots\ldots m; \\ & y_{fo} \leq \sum_{j=1,j\neq 0}^{n}\omega_j y_{rj} + s_r^{+} \qquad r=1,2,3\ldots\ldots q; \\ & b_{go} \geq \sum_{j=1,j\neq o}^{n}\omega_j b_{kj} - s_k^{+} \qquad k=1,2,3\ldots\ldots h; \\ & \omega_j \geq 0,\ s_e^{-} \geq 0,\ s_f^{+} \geq 0,\ s_g^{+} \geq 0 \end{aligned} \tag{7}$$

Where: $X \in R^{m\times n}$ is the data-entry matrix, $s_f^{+} \in R^{q\times n}$ is the anticipated result matrix, $s_g^{+} \in R^{h\times n}$ is the unwanted output matrix, $s_e^{-} \in R^{m}$, $s_f^{+} \in R^{q}$ and $s_g^{+} \in R^{h}$ stand for the associated surplus (or slack) variables. The indices e, f, and g correspond to the count of input factors, anticipated outputs, and unfavorable outputs, respectively. Specifically, i ranges from 1 to q, r ranges from 1 to m, and k ranges from 1 to h. x_{io} , y_{ro} and b_{ko} signify the respective outputs. ω represents the weight vector, and θserves as the goal function. $\sum_{j=1,j\neq o}^{n}\omega_j x_{ij}$, $\sum_{j=1,j\neq o}^{n}\omega_j y_{rj}$ and $\sum_{j=1,j\neq o}^{n}\omega_j b_{kj}$ represent the virtual effective decision-making unit, i.e., ωx 、 ωy, and ωb as the ideal benchmark framework. Once the excess variables are set to zero, the goal function achieves the most favorable solution. Specifically, the target function equals 1, which implies that the DMU is efficient. Conversely, if the target function lies within the open interval (0, 1), it indicates that the DMU experiences an efficiency shortfall.

3.2.1. Establishment of Spatial Econometric Model

The preceding theoretical scrutiny indicates that NQP and SEEP exhibit certain spatial spillover effects. Consequently, this study adopts the spatiotemporal panel model to examine the influence of NQP on SEEP. Initially, the existence of spatial correlation is verified. In the event that spatial correlation is detected, the spatial econometric model (Li *et al.*, 2023a) is selected for further analysis. Conversely, if no spatial correlation is found, the ordinary panel model is employed. To put it another way, when spatial correlation is absent, regression analysis will be conducted using the ordinary panel model. Moran's I statistic, which is used for detecting spatial autocorrelation patterns, is presented in equation (8):

$$I = \frac{\sum_{m=1}^{n}\sum_{l=1}^{n}w_{ml}\left(x_m-\bar{x}\right)\left(x_l-\bar{x}\right)}{s^2\sum_{m=1}^{n}\sum_{l=1}^{n}w_{ml}} \tag{8}$$

Where: $s^2 = \frac{\sum_{l=1}^{n}\left(y_m-\bar{y}\right)}{n}$ represents the sample variance, w_{ij} denotes the (m, l) component of the geographical weighting matrix. In the case where the spatial weighting matrix undergoes row-standardization, then $\sum_{m=1}^{n}\sum_{l=1}^{n}w_{ml} = n$. Moran's coefficient typically falls within the interval (-1, 1).

Following the spatial dependence examination, a series of statistical tests, namely the LM, Hausman, LR, and Wald tests, were carried out sequentially to identify a suitable spatial econometric model. The standard formulations for both the conventional panel and the spatial panel models are presented in equations (9) through (12):

$$\mathrm{SEEP}_{it} = \alpha + \beta \mathrm{NQP}_{it} + \theta Z_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (9)$$

$$\mathrm{SEEP}_{it} = \alpha + \beta \mathrm{NQP}_{it} + \rho W \times \mathrm{SEEP}_{it} + \theta Z_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (10)$$

$$\mathrm{SEEP}_{it} = \alpha + \beta \mathrm{NQP}_{it} + \theta Z_{it} + \mu_i + \nu_t + \varepsilon_{it}, \quad \varepsilon_{it} = \rho W \times \varepsilon_{it} + \sigma_{it} \quad (11)$$

$$\mathrm{SEEP}_{it} = \alpha + \beta \mathrm{NQP}_{it} + \rho W \times \mathrm{SEEP}_{it} + \gamma W \times \mathrm{NQP}_{it} + \theta Z_{it} + \theta_1 W \times Z_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (12)$$

Four spatial econometric models are employed: (9) the conventional panel model (baseline); (10) the SAR model, which captures spatial spillovers via a spatially lagged dependent variable; (11) the SEM model, which addresses spatial autocorrelation in error terms from unobserved spatial factors; and (12) the SDM model, which integrates both SAR and SEM features to comprehensively analyze spillovers of both dependent and independent variables. In all models, Z denotes the regulated variable, with spatial lag components for SEEP, NQP, and Z; μ_i and ν_t represent fixed effects, and ε_{it} is the stochastic disturbance term.

$$\mathrm{M}_{it} = \alpha_1 + \beta \mathrm{N}QP_{it} + \rho W \times \mathrm{M}_{it} + \sigma Z_{it} + \mu_{1i} + \nu_{1t} + \varepsilon_{1it} \quad (13)$$

Equations (13) define the expression of the transmission mechanism. Each variable is preceded by its estimated regression parameter. Specifically, Statistical inference on the β parameter reveals the causal impact of the underlying driving process.

3.3. *Variable declaration*

3.3.1. *Dependent variable*

Referring to the Accounting Standards for the Total Value of EPR formulated by the National Development and Reform Commission, combined with the connotation and characteristics of EPR, and drawing on existing research, this paper constructs an index system for the SEEP. The input indicators include material capital input, land input, labor input, and energy input. The output indicators are divided into expected output and undesired output. The details are as follows.

(1) Input indicators. ①Physical capital (investment in fixed assets of agriculture, forestry, animal husbandry, and fishery), which reflects the physical capital invested in the production process of EPR. According to the concept of EPR, this indicator can better describe the material basis of the supply of EPR. ②Land input (various types of ecological land area), reflecting the natural resource endowment. ③Labor input (the number of employees in the primary industry and ecotourism), reflecting the human resource input needed for the production and service supply of EPR. ④Energy input (agriculture, forestry, animal husbandry, and fishery, accommodation and catering energy terminal consumption, 10,000 tons of standard coal), reflecting the energy consumption intensity of EPR from production to service. All data sources are clearly marked (see **Table 2**).

Table 2. SEEP's Indicator Framework.

Selection of input/output	Indicators	Units
Financial capital expenditure	Capital outlay on agricultural, forestry, livestock-farming, and aquaculture fixed assets	Billion yuan
Workforce allocation	Headcount within the primary sector and the eco-tourism domain	Million people
Territorial resource input	Diverse categories of ecological land acreage	10^3 hm^2
Energy resource consumption	Final energy utilization in the sectors of agriculture, forestry, livestock farming, fisheries, as well as lodging and catering	10,000 metric tons of coal criterion
Expected output	A holistic indicator encompassing ecological agricultural, forestry, livestock, and fisheries outputs, along with measures of eco-tourism, air quality compliance, and superior water quality rates	—
Undesired output	An all-encompassing indicator encompassing the scale of soil-eroded regions, wastewater, waste gas emissions, the density of inhalable particulate matter, PM2.5, and the intensity of noise across each province	—

(2) Expected output. The comprehensive index synthesized by the entropy weight TOPSIS method includes three dimensions: ①the output value of ecological agriculture, forestry, animal husbandry, and fishery products (material supply); ②ecotourism income (service supply); ③air compliance rate and water quality excellent rate (regulating service supply).

(3) Undesired output. The comprehensive index synthesized by the entropy weight TOPSIS method includes six sub-indicators: soil erosion area, wastewater discharge, exhaust emissions, PM10, PM2.5, and noise level, reflecting the negative environmental effects associated with the supply of EPR.

Notably, since the SBM model generally requires that the number of decision-making units be 3–5 times the number of indicators, this paper aggregates relevant indicators into comprehensive indices for expected and undesired outputs before estimating the SEEP.

3.3.2. Key explanatory factors

NQP is an innovation-driven advanced productivity form featuring high technology, efficiency, and quality, which breaks traditional growth modes and aligns with the new development philosophy. Given the absence of unified measurement standards in existing literature, a four-dimensional comprehensive index covering development potential, capability, strength, and momentum is constructed following prior research (Liang and Zhu, 2024; Lu *et al.*, 2024; Zhu *et al.*, 2024), with detailed indicators listed in **Table 3**. Specifically, academic publications measure potential, invention patents per 10,000 people reflect capability, high-tech industry share, and economic transformation denote strength, while R&D funding from governments and enterprises represents momentum. The entropy-weighted TOPSIS method (Li *et al.*, 2023b) is adopted to calculate the NQP composite index for higher accuracy. A preliminary correlation test on all indicators (see Appendix A) rules out severe multicollinearity. Before conducting the formal measurement, this research conducts a comprehensive correlation test on the relevant variables within the indicator system (see Appendix A for details). The test results indicate that there is no high correlation among the variables.

Given that the multicollinearity problem prevalent in multivariate analysis may compromise the accuracy and stability of the estimation, this paper employs principal component analysis (PCA) to measure NQP as a robustness test. Compared with the comprehensive score obtained by the entropy weight TOPSIS method, which has a clear economic meaning (i.e., the closeness to the ideal solution), the PCA principal component, as a linear combination of the original indicators, has a relatively vague economic meaning. Therefore, it is more suitable as a robustness test tool to eliminate multicollinearity rather than as a principal estimation method. For data processing, min-max standardization is adopted in the main regression to map indicators into the [0, 1] interval, preserving the original distribution pattern while remaining robust to moderate outliers. As a sensitivity test, a z-score standardized re-estimation model with non-negative translation is further employed to ensure compatibility with the entropy weight method, serving as an additional robustness check.

Table 3. Framework for Assessing the Level of NQP.

Primary Indicators	Secondary Indicators	Tertiary Indicators	Units	Attribute
NQP level	Potential dimension	Published scientific papers	Piece	+
		Number of Chinese "Two Yuan" academicians	Person	+
		Share of enterprises engaging in research and development endeavors	%	+
	Capability dimension	Number of inventions and authorized patents by 10,000 people	Pieces/ten thousand people	+
		Coefficient of the national science and technology achievement award	Item equivalent/10,000 people	+
		Ten thousand technical transactions	Thousand households	+
	Strength dimension	High-tech industry-added value accounted for a proportion of the industrial-added value	%	+
		Labor productivity	%	+
		Productivity of capital	%	+
		National University Science Park - net fixed assets at year-end	Thousand Yuan	+
	Momentum dimension	Sources of funding for research and experimental development from government, business, foreign, and other funds	Ten thousand yuan	+
		Comparative coefficient of average wages in scientific research and technical services	%	+

3.3.3. Mechanism variables

This study identifies four mechanism variables in the NQP→SEEP pathway: (1) workforce capital (Hc: share of higher-educated labor); (2) industrial structure (Ti: share of the service sector); (3) government capacity (Gr: local fiscal revenue); and (4) enterprise income (Tp: operating profit). Since Gr and Tp are absolute values prone to heteroscedasticity, both are log-transformed to ensure estimation reliability.

3.3.4. Control variables

Seven control variables are included: education (Edu): ratio of local to national colleges; technology (Tec): share of regional patent applications; information (Inf): share of postal and telecom services; economic development (Ed): per capita GDP; urbanization (Urb): urban population ratio; population concentration (Pop): population density; and environmental regulation (Env): pollution control investment/industrial value-added (Song *et al.*, 2021; Sun and Wu, 2020). All controls are expressed as relative values for cross-regional comparability. The instrumental variable is the mean NQP of other provinces within the same region and year. Summary statistics are provided in Appendix B.

4. Empirical test

4.1. *Spatial correlation test*

Before the spatial correlation test, panel unit root tests, cointegration tests, and multicollinearity tests were also conducted, with all results confirming the validity of the data (see Appendix C). For a more precise depiction of the interaction among spatial entities, this study takes into account the impact of distance and opts for the economic geographical weight matrix. The global spatial correlation of SEEP and NQP was measured. The global Moran's I indices are detailed in **Table 4**.

Table 4. Results of the global spatial correlation test.

	Variables	I	E(I)	Sd(I)	z	P-value
Moran's I	SEEP	0.154	-0.003	0.040	3.958	Less than 0.001
	NQP	0.222	-0.003	0.039	5.747	Less than 0.001
	Variables	c	E(c)	Sd(c)	z	P-value
Geary's c	SEEP	0.833	1.000	0.051	-3.252	0.001
	NQP	1.484	1.000	0.105	4.628	Less than 0.001

Table 5. Results of the local spatial correlation test.

Variables	SEEP			NQP		
	I	Z	p-value*	I	Z	p-value*
2011	0.044	0.838	0.201	0.020	0.995	0.160
2012	0.050	0.905	0.183	0.045	1.619	0.053
2013	0.022	0.610	0.271	0.102	2.094	0.018
2014	0.052	0.933	0.175	0.115	2.204	0.014
2015	0.034	0.725	0.234	0.169	2.948	0.002
2016	0.119	1.633	0.051	0.175	2.867	0.002
2017	0.169	2.179	0.015	0.174	3.064	0.001
2018	0.063	1.045	0.148	0.055	1.194	0.116
2019	0.169	2.262	0.012	0.059	1.274	0.101
2020	0.161	2.090	0.018	0.059	1.219	0.111
2021	0.211	2.604	0.005	0.073	1.339	0.090
2022	0.148	1.930	0.027	0.106	1.681	0.046

Meanwhile, to discern the spatial interdependence between a specified region and its adjacent regions, this study further computed the local Moran's index measure of SEEP and NQP. The results indicate that both the SEEP and NQP not only exhibit significant spatial correlation as a whole but also present local variations under global autocorrelation. The global Moran's I indices are detailed in **Table 5**.

4.2. *Analysis of empirical results*

The Lagrange multiplier (LM) test is adopted to select the optimal spatial econometric model relative to the mixed OLS specification. Insignificant spatial lag and spatial error terms suggest the adoption of the OLS model. Significance limited to the spatial error term points to the SEM model, whereas sole significance of the spatial lag term supports the SAR model. Where both basic LM tests return significant results, the robust LM test is applied for model discrimination. If the robust LM test yields significant outcomes, the LR and Wald tests are further implemented; significant results from both tests justify the adoption of the SDM. The Hausman test determines the selection between random and fixed effects, and a significant p-value rejects the null hypothesis in favour of the fixed-effects model. Following these sequential specification tests, the spatial lag model is confirmed as the optimal model for this research. The model selection test results are reported in Appendix D.

The estimation outcomes of the conventional panel regression model and the spatial lag model are presented in **Table 6**. Column (1) displays the outcomes of the conventional panel regression. The findings indicate that the impact coefficient of the NQP is positive and statistically significant, indicating that the NQP can enhance the improvement of the SEEP. Therefore, Hypothesis 1 is verified. Columns (2) to (7) represent the SAR fixed-effect models, some of which include control variables and some of which do not. Based on the findings derived from the R^2 estimation outcomes, while accounting for the influence of spatial effects and control variables to the greatest extent feasible, this study adopts the regression outcomes presented in **Table 6** (7) as the benchmark. The outcomes reveal that the Spatial rho coefficient attains statistical significance. This implies that the SEEP in specific regions is influenced by its counterpart in neighboring regions, and there exists a pronounced spatial interdependence between them. The NQP's regression parameter is notably positive, suggesting that as NQP develops, the SEEP experiences further enhancement, thereby validating hypothesis 2. It also indicates that an improvement in regional NQP can drive the advancement of local SEEP. From the regression findings regarding regulating variables, the educational level has a considerable positive impact on the SEEP. The levels of "tec" and "env" exert a beneficial effect on the SEEP, while the levels of urbanization and population density exert a detrimental effect, albeit not significantly.

Table 6. Results of panel-based spatial influence regression.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
NQP	1.695*** (0.566)	1.213** (0.556)	1.171** (0.565)	1.122*** (0.337)	0.924* (0.529)	1.158*** (0.378)	1.539*** (0.538)
edu	34.550*** (7.003)		31.54*** (7.112)		2.360 (4.186)		33.15*** (6.616)
tec	1.299 (0.986)		1.201 (0.904)		1.784** (0.873)		1.227 (0.928)
urb	-0.166 (0.317)		0.589 (0.707)		0.519 (0.548)		-0.223 (0.300)
pop	4.606 (6.104)		9.826 (6.572)		-0.602 (0.955)		5.028 (5.743)
env	3.068 (3.940)		5.334 (4.009)		4.361 (4.351)		3.157 (3.705)
Spatial rho		0.065 (0.090)	-0.018 (0.091)	0.225*** (0.080)	0.171** (0.084)	0.217*** (0.081)	0.177** (0.081)
Variance sigma2_e		0.028*** (0.002)	0.026*** (0.001)	0.032*** (0.002)	0.031*** (0.002)	0.030*** (0.002)	0.027*** (0.002)
Individual fixed	Yes	No	No	Yes	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes	No	No	Yes	Yes
Control variables	Yes	No	Yes	No	Yes	No	Yes
Within R^2	0.120	0.040	0.104	0.042	0.083	0.042	0.125
N	360	360	360	360	360	360	360

*Note: (1) represents the ordinary panel regression, while (2) to (7) represent the spatial lag model regressions. It is within parentheses that the standard errors are placed. Also, * means p < 0.1, ** shows p < 0.05, and *** stands for p < 0.01 (this notation is also applicable to the tables that follow).*

Table 7. Spatial influence breakdown of panel data regression outcomes.

Variables	Direct consequence		Indirect consequence		Total consequence	
	Coefficients	SEs	Coefficients	SEs	Coefficients	SEs
NQP	1.551***	(0.541)	0.322*	(0.180)	1.873***	(0.635)
edu	32.70***	(5.668)	7.218*	(4.211)	39.92***	(7.909)
tec	1.317	(1.028)	0.272	(0.277)	1.589	(1.240)
urb	-0.204	(0.312)	-0.0460	(0.0848)	-0.250	(0.386)
pop	3.830	(6.737)	0.882	(2.086)	4.712	(8.597)
env	3.440	(3.610)	0.794	(0.911)	4.233	(4.397)

Using the partial differential method, the spatial lag results are decomposed into direct, indirect (spillover), and total effects (**Table 7**). All three effects of NQP on SEEP are positive and significant, confirming that NQP improves SEEP both locally and in neighboring regions, though the local effect dominates. This is because, at the early stage of NQP development, factor agglomeration primarily benefits the local area, while the integration of new quality productivity with EPR supply and the spillover of digital infrastructure remain underdeveloped, constraining cross-regional spillovers. Among controls, education (Edu) shows significantly positive direct and indirect effects, with the local effect being stronger—consistent with the pattern that educational clustering initially outweighs its dispersion effect, though spillovers are expected to grow over time.

5. Further discussions

5.1. *Robustness test*

5.1.1. Weight Matrix Transformation

Beyond creating the inverse-distance spatial proximity matrix, this study also establishes the adjacency, nested, and economic-geographic spatial proximity matrices. These matrices are subsequently incorporated into the established baseline equations. By conducting step-by-step regression analysis, it is observed that, regardless of the matrix employed, the beneficial impact of NQP on the SEEP is statistically notable, and the attributes remain consistent. This demonstrates the reliability of the results obtained from the SAR using the economic-geospatial weight matrix. **Tables 8 (a) to (c)** present the regression findings for different proximity matrices.

Table 8. Regression findings of the transformed weight matrix and the exclusion of outliers.

Variables	(a)		(b)		(c)		(d)	
	Coefficients	**SEs**	**Coefficients**	**SEs**	**Coefficients**	**SEs**	**Coefficients**	**SEs**
NQP	1.680***	(0.538)	1.586***	(0.538)	1.720***	(0.533)	1.538***	(0.537)
Spatial rho	0.037	(0.071)	0.160*	(0.087)	0.158**	(0.075)	0.177**	(0.081)
Variance sigma2_e	0.028***	(0.002)	0.028***	(0.002)	0.027***	(0.002)	0.027***	(0.002)
Fixed effect	Yes		Yes		Yes		Yes	
N	360		360		360		360	

Note: The regression outcomes (a)-(c) represent the results derived from regressions conducted using the adjacency-based, nested, and economic-geographic types of the spatial weight matrix, respectively. (d) represents the SAR regression result of the data after tail reduction processing.

5.1.2. Eliminating Outlier Interference

To eradicate the impact of deviations within the benchmark regression findings, the comprehensive indices of SEEP, NQP, and covariate are trimmed at the 1% level. Subsequently, the model can be re-estimated. **Table 8 (d)** presents the results. Following data cleansing, it is observed that the essence of the regression results remains unaltered, thereby confirming the robustness of the aforementioned conclusions.

5.1.3. Substitution variable

The dependent variables are substituted with the outcomes derived from the SBM-based measurement of undesirable output (SEEP1) and the supply degree of EPR (SEEP2). The core explanatory variable is replaced in four ways: ①NQP1 constructed via Z-score standardization and the entropy weight method; ②NQP2 via min-max standardization and the entropy weight method; ③NQP3 via min-max standardization and PCA; and ④NQP4, using digital economy development level as a proxy for new quality productive forces (Wang and Yang, 2023). The underlying logic is twofold: first, re-estimating the model using alternative measurement methods for the relevant indicators; second, re-estimating the model with alternative proxies for the core explanatory variable. The results are reported in **Table 9**. Additionally, a leave-one-out sensitivity analysis is conducted by sequentially excluding each secondary index from the NQP index system, recalculating the composite index, and re-estimating the model (see Appendix E for details). The resulting coefficients remain consistent in direction and statistical significance, further confirming the robustness of the baseline findings.

5.1.4. Testing the endogeneity

To address potential endogeneity, this study employs three distinct econometric approaches.

First, using the Instrumental Variable (IV) method, the estimation outcomes are displayed in columns (1) and (2) of **Table 10**. It indicates that the coefficient of NQP is 3.846, which is positive and statistically significant at the 1% level. This confirms the reliability of the baseline regression findings. Second, the Spatial Lag GMM model yields a marginal effect of NQP on SEEP of 1.513, which remains statistically significant. Additionally, the spatial lag coefficient of SEEP is significantly positive, indicating strong spatial dependence. The pertinent regression findings are displayed in **Table 10(3)**. Third, the Dynamic Spatial Autoregressive (DSAR) model shows that the influence coefficient of NQP on SEEP is 1.763, demonstrating a significant positive relationship. The lagged dependent variable coefficient (0.318) and the spatial autocorrelation coefficient (0.173) are also significantly positive, verifying the dynamic continuity and spatial agglomeration effects of SEEP. The comprehensive regression outcomes are exhibited in **Table 10(4)**.

Collectively, the results from these three models consistently demonstrate that NQP has a significant positive impact on SEEP, confirming that the initial regression outcomes are robust and not affected by endogeneity issues.

5.2. *Mechanism examination*

To verify Hypothesis 3, Equation (13) is estimated (**Table 11**). The results confirm four mediating channels through which NQP enhances SEEP. First, NQP significantly improves workforce capital composition (Column 2: $\beta = 0.083$, $p < 0.1$), as advanced human capital strengthens ecological awareness (Zhong *et al.*, 2026), supporting Hypothesis 3a. Second, NQP significantly promotes industrial structure upgrading (Column 3: $\beta = 0.854$, $p < 0.01$), as green production and consumption reduce emissions and boost resource efficiency (Huang *et al.*, 2026; Li *et al.*, 2026; Ma *et al.*, 2026), supporting Hypothesis 3b. Third, NQP significantly increases both local government fiscal revenue (Column 4: $\beta = 0.948$) and enterprise operating profit (Column 5: $\beta = 3.524$), thereby stimulating EPR supply enthusiasm from both governments and enterprises(Yan *et al.*, 2025), supporting Hypotheses 3c and 3d.

Standardized coefficients further reveal the relative importance of each channel: industrial structure upgrading exerts the strongest influence, followed by EPR supply enthusiasm (government and enterprises), while workforce capital plays a smaller yet non-negligible role.

These mechanisms are intertwined and jointly drive SEEP improvement.

5.3. *Heterogeneity discussion*

The preceding analysis indicates that the NQP exerts a notable spatial spillover influence on the SEEP across China. To examine whether there exist regional disparities in the SEEP among the three major geographical divisions (eastern, central, and western) of China (the geographical distribution map of these regions is presented in **Figure 2b**), this study constructs an inverse-distance spatial weighting matrix and performs spatial regression analysis in econometrics on each region separately. (Dian *et al.*, 2024). The findings are presented in **Table 12** below. The visual graph is shown in **Figure 3**.

Table 9. Regression findings of replacing associated variables.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	SEEP1	SEEP2	SEEP	SEEP	SEEP	SEEP
NQP	1.847*** (0.677)	0.112* (0.0614)				
NQP1			1.599*** (0.525)			
NQP2				0.920** (0.452)		
NQP3					2.229*** (0.606)	
NQP4						(0.254)
Spatial rho	0.136* (0.0757)	0.217*** (0.0668)	0.165** (0.075)	0.157** (0.0761)	0.160** (0.0755)	0.149* (0.0762)
Variance sigma2_e	0.045*** (0.003)	0.0004*** (Less than 0.001)	0.028*** (0.002)	0.028*** (0.002)	0.027*** (0.002)	0.028*** (0.002)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	360	360	360	360	360	360

Table 10. Regression results of endogenous tests.

Variables	(1)	(2)	(3)	(4)
	NQP	SEEP	SEEP	SEEP
IV	0.180*** (0.018)			
NQP		3.846*** (1.309)	1.513*** (0.502)	1.763*** (0.555)
Kleibergen-Paap rk LM statistic	22.816 (Chi-sq(1) P-val = 0.0000)			
Cragg-Donald Wald F statistic	63.817			
Kleibergen-Paap rk Wald F statistic	95.670			
Stock-Yogo weak ID test critical values: 10% maximal IV size	16.38			
SEEP. L1.			0.245* (0.145)	0.318*** (0.113)
w1y_SEEP			3.414** (1.589)	
Rho value			0.003** 4.615（Chi2 test) 0.032（P value）	0.173*** (0.044)
Variance sigma2				0.028*** (0.005)
Control variables	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes
N	360	360	360	360

Note: (1) and (2) are two-stage regression of instrumental variables, (3) is spatial dynamic GMM regression, and (4) is dynamic spatial lag regression.

Table 12 (1) and (3) show that NQP has a significant positive impact on the SEEP in the eastern region, and it has a greater marginal impact on the western region. The eastern region has a solid foundation for innovation, has applied NQP-related technologies early, and has a mature EPR supply system. Although the positive promoting effect of new technologies is significant, the marginal promotion space is limited. The original EPR supply foundation in the West is weak. After the introduction of NQP technologies, it can quickly break through the old bottleneck and bring about a greater marginal improvement effect. **Table 12 (2)** shows that the development of NQP has a positive impact on the SEEP in the central regions, but it is not significant. The NQP level in Central China (below 0.116) likely has not yet crossed the threshold needed to significantly boost SEEP, consistent with the "threshold effect" in innovation–environment literature. Although the central region actively introduces NQP-related factors, the integration of industrial supporting capabilities and innovation capabilities is insufficient, making it difficult to efficiently transform them into a substantial improvement in the SEEP (Lu *et al.*, 2024). Therefore, the positive impact is not significant. To sum up, the impact imposed by the advancement level of the NQP on the SEEP exhibits significant regional distinctions among the eastern, central, and western areas. Therefore, hypothesis 4 is verified.

Table 11. Regression results of the mechanism test.

Variables	(1) SEEP	(2) Hc	(3) Ti	(4) lnGr	(5) lnTp
NQP	1.539*** (0.538)	0.083* (0.049)	0.854*** (0.039)	0.948*** (0.322)	3.524** (1.454)
NPQ-std	0.419*** (0.130)	0.096* (0.0579)	0.829*** (0.038)	0.097*** (0.033)	0.273** (0.113)
Spatial rho	0.177** (0.081)	0.587*** (0.049)	-0.338*** (0.073)	0.400*** (0.044)	0.269*** (0.066)
Variance sigma2	0.027*** (0.002)	0.0002*** (Less than 0.001)	0.001*** (Less than 0.001)	0.074*** (0.006)	0.192*** (0.014)
Control variables	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes
N	360	360	360	360	360

Note: Utilizing model selection, columns (1) - (4) are employed for the SAR model, whereas column (5) is utilized for the SDM model.

Table 12. Regression outcomes from the Heterogeneity examination.

Variables	(1) Eastern area		(2) Central area		(3) Western area	
	Coefficients	SEs	Coefficients	SEs	Coefficients	SEs
NQP	1.394^{**}	(0.641)	1.357	(1.864)	3.638^{**}	(1.548)
Spatial lambda	0.151^{*}	(0.102)			0.198^{*}	(0.106)
Spatial rho			-0.235^{**}	(0.019)		
Variance sigma2_e	0.028^{***}	(Less than 0.001)	0.017^{***}	(Less than 0.001)	0.028^{***}	0.003
Control variables	Yes		Yes		Yes	
Fixed effect	Yes		Yes		Yes	
N	132		96		132	

Note: For model selection, the SEM is used for the Eastern and Western areas, whereas the SAR is used for the Central region (see Appendix F for test results).

6. Conclusions and revelations

6.1. *Conclusions*

Using panel data from 30 Chinese provinces (2011–2022), this study examines how NQP affects SEEP via the super-SBM model, entropy-weighted TOPSIS, and spatial econometric analysis. Four key findings emerge: (1) SEEP varies substantially across provinces (national mean: 0.575), while NQP development remains low nationwide (mean: 0.115). (2) NQP exerts a significant positive spatial spillover on SEEP, benefiting both local and neighboring regions. (3) NQP enhances SEEP through four channels: workforce capital upgrading, industrial structure optimization, fiscal revenue growth, and enterprise income improvement. (4) The NQP–SEEP nexus is significant in eastern and western China but insignificant in central regions, revealing pronounced regional heterogeneity. This conclusion provides an important factual reference for how NQP enables the improvement of SEEP in China.

6.2. *Revelations*

Based on the empirical findings—particularly the regional heterogeneity (significant only in eastern China) and the four transmission channels (human capital, industrial structure, fiscal revenue, and enterprise income)—the following differentiated and actionable recommendations are proposed:

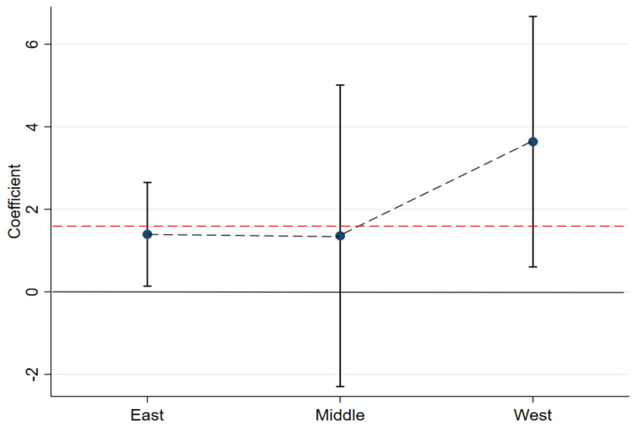


Figure 3. Visualization results of heterogeneity. The solid dot represents the marginal coefficient, the short vertical line represents the 95 % confidence interval, and the red dotted line is the coefficient of digital technology innovation based on the benchmark regression.

(1) Prioritize NQP-driven green innovation in eastern China, where the effect is significant. Eastern provinces should leverage their strong NQP base to lead green technological breakthroughs. Specifically, governments should establish

provincial-level NQP innovation funds (e.g., matching 30% of enterprise R&D expenditure) and create green technology transfer platforms to convert NQP gains into SEEP improvements.

(2) Address the “threshold effect” in central and western China, where the impact is insignificant. The insignificant results suggest that NQP has not yet reached the critical mass needed to improve SEEP in these regions. Therefore, priority should be given to building foundational NQP capacity—specifically, investing in vocational training programs (to upgrade workforce capital, the weakest channel) and attracting NQP-related enterprises through tax incentives, rather than directly pushing for green transformation.

(3) Exploit the spatial spillover effect through targeted interregional cooperation. Since NQP benefits neighboring regions, eastern and western provinces should be incentivized to share green patents and clean technologies with central provinces through a cross-provincial NQP cooperation mechanism (e.g., joint industrial parks or technology licensing subsidies), rather than generic “regional cooperation”.

(4) Strengthen the fiscal and enterprise channels simultaneously. The mechanism analysis shows that fiscal revenue and enterprise income are key mediators. Thus, local governments should tie environmental performance to fiscal transfers (e.g., bonus subsidies for provinces achieving SEEP improvements) and reduce the tax burden on green enterprises to enhance their operating income, thereby reinforcing the NQP→SEEP pathway.

6.3. *Research prospect*

Current EPR academic research in China remains at the preliminary stage, focusing on concept definition, value accounting, and value realization mode discussion. Relevant research on NQP mainly focuses on connotation interpretation and level measurement, while empirical studies on NQP’s ecological efficiency effect are still insufficient. This paper complements quantitative empirical evidence on how NQP reshapes EPR supply efficiency and clarifies multi-path action mechanisms. To deepen relevant research, subsequent studies will focus on the whole-chain value realization benefit of EPR driven by NQP, and explore differentiated value transformation modes under diverse regional scenarios.

Disclosure of Interest

The authors report there are no competing interests to declare.

Funding

This study was supported by the 2025 Annual Project of Philosophy and Social Science Planning in Guizhou Province: "Study on the Current Situation, Problems, and Optimization Path for the Industrialized Utilization of Agricultural and Tourism Resources in Guizhou" (Grant No. 25GZQN01).

Data Availability

The data supporting the findings of this study are derived from publicly available official sources, including the China Statistical Yearbook, China Science and Technology Statistical Yearbook, China Energy Statistical Yearbook, China Population and Employment Statistical Yearbook, China Rural Statistical Yearbook, China Tourism Statistical Yearbook, Ecological Environment Bulletin, Soil and Water Conservation Bulletin, Natural Resources Bulletin, and Compilation of Science and Technology Statistical Data, as well as provincial-level statistical yearbooks and bulletins. Processed datasets are available from the corresponding author upon reasonable request.

Author Contributions

Jingbo Shao: Conceptualization, Methodology, Formal Analysis, Data Curation, Writing – Original Draft. Xue Lei: Supervision, Writing – Review & Editing, Funding Acquisition. All authors read and approved the final manuscript.

References

Ambec S, Barla P (2006) Can environmental regulations be good for business? An assessment of the Porter hypothesis. Energy studies review 14. http://doi.org/10.15173/esr.v14i2.493

Bai F, Gao P, Zheng W (2023) Ecological resources enabling rural common prosperity: The promoting role of digital economy (in Chinese). Journal of China Agricultural University 28: 263-275. http://doi.org/0.11841/j.issn.1007-4333.2023.06.23

Behrens K, Thisse J-F (2007) Regional economics: A new economic geography perspective. Regional Science and Urban Economics 37: 457-465. http://doi.org/10.1016/j.regsciurbeco.2006.10.001

Ciccone A, Peri G (2006) Identifying human-capital externalities: Theory with applications. The Review of Economic Studies 73: 381-412. http://doi.org/10.1111/j.1467-937X.2006.00380.x

Dian J, Song T, Li S (2024) Facilitating or inhibiting? Spatial effects of the digital economy affecting urban green technology innovation. Energy Economics 129. http://doi.org/10.1016/j.eneco.2023.107223

Dolbear F T (1967) On the theory of optimum externality. The American Economic Review 57: 90-103. http://doi.org/https://www.jstor.org/stable/1815607

Du C, Guo Y (2023) Multi-center collaborative governance: Also research on the innovation path of ecological product supply in watershed-take the Yangtze River economic belt as an example (in Chinese). Journal of the Party School of Tianjin Committee of the CPC 25: 86-95. http://doi.org/10.16029/j.cnki.1008-410X.2023.03.009

Fang G, Yang K, Chen G, Tian L (2023) Environmental protection tax superseded pollution fees, does China effectively abate ecological footprints? Journal of Cleaner Production 388: 135846. http://doi.org/10.1016/j.jclepro.2023.135846

Gao F (2023) The logic, multidimensional connotation and current significance of “new quality productivity” (in Chinese). China Review of Political Economy 14: 127-145.

Guaita Martínez J M, Puertas R, Martín Martín J M, Ribeiro-Soriano D (2022) Digitalization, innovation and environmental policies aimed at achieving sustainable production.

Sustainable Production and Consumption 32: 92-100. http://doi.org/10.1016/j.spc.2022.03.035

He Y, Ruan J, Xie S, Xu M, Chen X et al (2022a) Economic effects of marine ecological product policies: improving supply efficiency and realizing common prosperity —Data analysis based on China's coastal provinces (in Chinese). Marine Sciences 46: 74-87. http://doi.org/10.11759/hykx20220824004

He Y, Zhang Y, Li C (2022b) Supply efficiency of water ecological products and its influencing factors in Zhoushan City based on RSBM-DEA model (in Chinese). Water Resources Protection 38: 195-203. http://doi.org/10.3880/j.issn.10046933.2022.04.027

Huang H, Yao S (2021) Measuring the efficiency of ecologically oriented rural public goods supply and its influencing factors (in Chinese). Journal of Northwest A&F University(Social Science Edition) 21: 104-112. http://doi.org/10.13968/j.cnki.1009-9107.2021.05.12

Huang L, Zeng H, Hu J, Yan H, Ma S (2026) When machines pay workers more: AI adoption and labor's rising share in Chinese manufacturing. Economics of Innovation and New Technology: 1-30. http://doi.org/10.1080/10438599.2026.2673096

Huang X, Lin Y, Lim M K, Zhou F, Ding R et al (2022) Evolutionary dynamics of promoting electric vehicle-charging infrastructure based on public–private partnership cooperation. Energy 239: 122281. http://doi.org/10.1016/j.energy.2021.122281

Jia R, Wang J, Dou H-t (2024) Promoting high-quality regional development by new productive forces [J/OL] (in Chinese). Reform: 1-10. http://doi.org/http://kns.cnki.net/kcms/detail/50.1012.F.20240314.0904.002.html.

Jin F, Ye Z, Chen Z, Ma L, Wang X (2024) Identification and spatial layout of the source-sink functions of new quality productive forces in the new era of China. Economic Geography 44: 8-16. http://doi.org/10.15957/j.cnki.jjdl.2024.08.002

Li D, Yan H, Zhang S (2026) Weaving the green thread: configurational drivers of sustainable transformation in the textile industry. Industria Textila 77: 68-82. http://doi.org/10.35530/IT.077.01.202576

Li G, Li M (2024) Provincial-level new quality productive forces in China: evaluation, spatial pattern and evolution characteristics. Economic Geography 44: 116-125. http://doi.org/10.15957/j.cnki.jjdl.2024.08.014

Li G, Li X, Huo L (2023a) Digital economy, spatial spillover and industrial green innovation efficiency: empirical evidence from China. Heliyon 9. http://doi.org/10.1016/j.heliyon.2023.e12875

Li X, Meng X, Ji X, Zhou J, Pan C et al (2023b) Zoning technology for the management of ecological and clean small-watersheds via k-means clustering and entropy-weighted topsis: a case study in Beijing. Journal of Cleaner Production 397: 136449. http://doi.org/10.1016/j.jclepro.2023.136449

Liang W, Zhu C (2024) The Logical connotation and monitoring framework of new productivity from the perspective of disruptive innovation ecosystem[J/OL] (in Chinese). Journal of Northwest University (Philosophy and Social Sciences Edition): 1-10. http://doi.org/https://link.cnki.net/urlid/61.1011.C.20240319.1356.002

Lin J Y (2011) New structural economics: A framework for rethinking development. The World Bank Research Observer 26: 193-221. http://doi.org/10.1093/wbro/lkr007

Liu K-d, Jin M, Cheng L (2025) County green transformation: how does gross ecosystem product assessment promote common prosperity? Humanities and Social Sciences Communications 12. http://doi.org/10.1057/s41599-024-04330-5

Liu Y, He Z (2024) Synergistic industrial agglomeration, new quality productive forces and high-quality development of the manufacturing industry. International Review of Economics and Finance: 103373. http://doi.org/10.1016/j.iref.2024.103373

Lu J, Guo Z, Wang Y (2024) Levels of development of new quality productivity, regional differences and paths to enhancement (in Chinese). Journal of Chongqing University (Social Science Edition): 1-16. http://doi.org/10.11835/j.issn.1008-5831.jg.2024.03.002.

Ma S, Li D, Yan H (2025) Entangled value: actor–network configurations and ESG pathways in China's textile value chain. The Journal of The Textile Institute: 1-13. http://doi.org/10.1080/00405000.2025.2587392

Ma S, Liu H, Zeng H, Li D, Yan H (2026) From Loom to Algorithm: How Digital Technologies Drive Quality Development in the Textile Sector. The Journal of The Textile Institute: 1-17. http://doi.org/10.1080/00405000.2026.2622882

Oates W E (1999) An essay on fiscal federalism. Journal of economic literature 37: 1120-1149. http://doi.org/10.1257/jel.37.3.1120

Ottaviano G (2003) Regional policy in the global economy: Insights from New Economic Geography. Regional Studies 37: 665-673. http://doi.org/10.1080/0034340032000108750

Ottaviano G I P, Thisse J-F (2005) New Economic Geography: What about the N? Environment and Planning A: Economy and Space 37: 1707-1725. http://doi.org/10.1068/a3730

Shen M, Ma N, Chen Q (2024) Has green finance policy promoted ecologically sustainable development under the constraints of government environmental attention? Journal of Cleaner Production 450: 141854. http://doi.org/10.1016/j.jclepro.2024.141854

Sheng R (2023) Efficiency of ecological products supply in China and its influencing factors from perspectives of technology innovation and institutional integration (in Chinese). Journal of Natural Resources 38: 2966-2985. http://doi.org/10.31497/zrzyxb.20231203

Song Y, Zhang X, Zhang M (2021) The influence of environmental regulation on industrial structure upgrading: Based on the strategic interaction behavior of environmental regulation among local governments. Technological Forecasting and Social Change 170: 120930. http://doi.org/10.1016/j.techfore.2021.120930

Sun C, Wu F (2020) Differences and convergence of matching development of high-class service industry and advanced manufacturing industry in China. Journal of Quantitative & Technological Economics 37: 3-24. http://doi.org/10.13653/j.cnki.jqte.2020.12.001

Tone K (2001) A slacks-based measure of efficiency in data envelopment analysis. European Journal of Operational Research 130: 498-509. http://doi.org/10.1016/s0377-2217(99)00407-5

Wang D, Huang C (2024) Promote the formation of new productive forces with the high-quality development of doctoral education (in Chinese). Academic Degrees & Graduate Education: 1-8. http://doi.org/10.16750/j.adge.2024.00.000

Wang J, Qiao L, Zhu G, Di K, Zhang X (2025) Research on the driving factors and impact mechanisms of green new quality productive forces in high-tech retail enterprises under China's Dual Carbon Goals. Journal of Retailing Consumer and Services 82: 104092. http://doi.org/10.1016/j.jretconser.2024.104092

Wang J, Wang Z, Liu G, Ma G, Wang X et al (2021) A Framework Research of Theory and Its Practice of the Fourth Industry of Ecological Products (in Chinese). Chinese Journal of Environmental Management 13: 5-13. http://doi.org/10.16868/j.cnki.1674-6252.2021.04.005

Wang Q, Yang J (2023) Research on digital new quality productivity and high-quality development of Chinese agriculture (in Chinese). Journal of Shaanxi Normal University (Philosophy and Social Sciences Edition) 52: 61-72. http://doi.org/10.15983/j.cnki.sxss.2023.1003

Wang Y, Sun X, Guo X (2019) Environmental regulation and green productivity growth: Empirical evidence on the Porter Hypothesis from OECD industrial sectors. Energy Policy 132: 611-619. http://doi.org/10.1016/j.enpol.2019.06.016

Wang Y, Wang Y (2020) An evaluation of supply efficiency of ecological public goods in Yangtze River economic belt--an empirical study based on three-phase DEA (in Chinese). Journal of Yangtze Normal University 36: 34-42+121. http://doi.org/10.19933/j.cnki.issn1674-3652.2020.03.004

Wei W, Wang N, Yin L, Guo S, Bo L (2024) Spatio-temporal evolution characteristics and driving mechanisms of Urban–Agricultural–Ecological space in ecologically fragile areas: A case study of the upper reaches of the Yangtze River Economic Belt, China. Land Use Policy 145: 107282. http://doi.org/10.1016/j.landusepol.2024.107282

Williamson J (1966) Profit, growth and sales maximization. Economica: 1-16. http://doi.org/10.2307/2552269

Wu B, Yang W (2022) Empirical test of the impact of the digital economy on China's employment structure. Finance Research Letters 49: 103047. http://doi.org/10.1016/j.frl.2022.103047

Xiao Z, Li H, Gao Y (2022) Analysis of the impact of the Beijing-Tianjin-Hebei coordinated development on environmental pollution and its mechanism. Environmental Monitoring and Assessment 194: 91. http://doi.org/10.1007/s10661-021-09720-9

Xu C, Yao X, Yan H, Li Y (2025a) Does ESG disclosure improve green innovation performance of new energy enterprises? Evidence from China. Polish Journal of Environmental Studie 34: 4859-4868. http://doi.org/10.15244/pjoes/190649

Xu J (2026) Rethinking development as structural transformation: a new structural economics perspective. World Development 204: 107406. http://doi.org/10.1016/j.worlddev.2026.107406

Xu J, Zhang J, Li X (2025b) Harnessing innovation and data: how do digital M&As fuel new quality productive forces. China Finance Review International. http://doi.org/10.1108/CFRI-10-2024-0619

Xu T, Yang G, Chen T (2024a) The role of green finance and digital inclusive finance in promoting economic sustainable development: A perspective from new quality productivity. Journal of Environmental Management 370: 122892. http://doi.org/10.1016/j.jenvman.2024.122892

Xu Y, Dai Q-Y, Lu Y-G, Zhao C, Huang W-T et al (2024b) Identification of ecologically sensitive zones affected by climate change and anthropogenic activities in Southwest China through a NDVI-based spatial-temporal model. Ecological Indicators 158: 111482. http://doi.org/10.1016/j.ecolind.2023.111482

Xu Y, Wen S, Tao C-Q (2023) Impact of environmental tax on pollution control: A sustainable development perspective. Economic Analysis and Policy 79: 89-106. http://doi.org/10.1016/j.eap.2023.06.006

Yan C, Ding Y, Liu X (2024) The spatial correlation of digital economy and its interaction with the development of real economy. China Business and Market: 1-13. http://doi.org/https://link.cnki.net/urlid/11.3664.F.20240320.0841.002

Yan H, Li Y, Zhong Y, Xia Z (2025) Will the 'government-court coordination'of corporate bankruptcy disposal improve ESG performance? Evidence from China. Applied Economics Letters 32: 2998-3002. http://doi.org/10.1080/13504851.2024.2358189

Yang R, Chen H, Chen S, Ye Y (2022) Spatiotemporal evolution and prediction of land use/land cover changes and ecosystem service variation in the Yellow River Basin, China. Ecological Indicators 145. http://doi.org/10.1016/j.ecolind.2022.109579

Yin H, Wu H (2021) The effective path choice of forest ecological products supply from the perspective of poverty alleviation based on empirical study of Heilongjiang province (in Chinese). Resource Development & Market 37: 136-140+145. http://doi.org/10.3969/j.issn.1005-8141.2021.02.002

Yue S, Bajuri N H, Khatib S F, Lee Y (2024) New quality productivity and environmental innovation: The hostile moderating roles of managerial empowerment and board centralization. Journal of Environmental Management 370: 122423. http://doi.org/10.1016/j.jenvman.2024.122423

Zellner A, Kmenta J, Dreze J (1966) Specification and estimation of Cobb-Douglas production function models. Econometrica: Journal of the Econometric Society: 784-795. http://doi.org/10.2307/1910099

Zhang J, Shan Y, Jiang S, Xin B, Miao Y et al (2024a) Study on the coordinated development degree of new quality productivity and manufacturing carbon emission efficiency in provincial regions of China. Environment, Development and Sustainability: 1-35. http://doi.org/10.1007/s10668-024-05321-x

Zhang L, Wang H (2023) The legal structure of ecological product value realization in the era of digital economy: taking "ant forest" as an example (in Chinese). Nanjing Journal of Social Sciences: 66-77. http://doi.org/10.15937/j.cnki.issn1001-8263.2023.07.008

Zhang X (2024) Technological innovation is the core element of developing new productive forces (in Chinese). Ideological & Theoretical Education: 20-26. http://doi.org/10.16075/j.cnki.cn31-1220/g4.2024.04.002

Zhang X, Fan H, Sun L, Liu W, Wang C et al (2024b) Identifying regional eco-environment quality and its influencing factors: A case study of an ecological civilization pilot zone in China.

Journal of Cleaner Production 435: 140308. http://doi.org/10.1016/j.jclepro.2023.140308

Zhang Y, Lian R (2023) Sustainable development of human capital structure and firm performance; —based on Chinese a-share listed companies. Theoretical Economics Letters 13: 549-567. http://doi.org/10.4236/tel.2023.133035

Zhang Y, Zhang Q (2023) Equilibrium analysis of multi-parties of interest conflicts and game in the operation of smart city PPP projects. Economic Change and Restructuring 56: 4009-4041. http://doi.org/10.1007/s10644-023-09509-5

Zhang Z, Li P, Wang X, Ran R, Wu W (2024c) New energy policy and new quality productive forces: A quasi-natural experiment based on demonstration cities. Economic Analysis and Policy 84: 1670-1688. http://doi.org/10.1016/j.eap.2024.10.039

Zhong Y, Qin B, Liu Z, Yan H (2026) Coordinating Bankruptcy Reform: Government–Court Collaboration and Firm Innovation through Financial and Human Capital Channels. Economic Analysis Policy and Politics. http://doi.org/10.1016/j.eap.2026.03.028

Zhong Y, Yan H, Xia Z (2025) Who is lifting the green veil? Climate physical risks and supply chain spillovers of corporate carbon greenwashing. Technology in Society: 103203. http://doi.org/10.1016/j.techsoc.2025.103203

Zhou C (2026) Toward Human-AI Collaboration for Sustainable Development: Unveiling the Drives of Artificial Intelligence Adoption in Environmental Governance. Sustainable Development n/a. http://doi.org/10.1002/sd.71277

Zhou C, Richardson-Barlow C (2026) A new framework for collaborative climate governance: linking consensus building and collective action. Policy & Politics: 1-22. http://doi.org/10.1332/03055736Y2026D000000089

Zhou F, Wang X (2022) The carbon emissions trading scheme and green technology innovation in China: A new structural economics perspective. Economic Analysis and Policy 74: 365-381. http://doi.org/10.1016/j.eap.2022.03.007

Zhou J, Guo J, Xu W (2025) Construction of big data comprehensive pilot zones, new quality productive forces and transformation of watershed resource–based cities: Double machine learning approach. Sustainable Cities and Society: 106144. http://doi.org/10.1016/j.scs.2025.106144

Zhu F, Li R, Xu X, Sun J (2024) Construction and spatiotemporal evolution of new productivity indicators of China (in Chinese). Journal of Industrial Technology and Economy 43: 44-53. http://doi.org/10.3969/j.issn.1004-910X.2024.03.005