This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

# The nonlinear effect of environmental regulations on urban green transformation in the Yellow River Basin

**Chengzhen Song**

**(The sole author and corresponding author)**

PhD

School of Geography and Tourism

Qufu Normal University

Rizhao 276826, China

Email: songcz198@126.com

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

# The nonlinear effect of environmental regulations on urban green transformation in the Yellow River Basin

**Abstract:** In order to better achieve regional sustainable development, it is extremely important to explore the relationship between environmental regulation (ENR) and urban green transformation. Nonetheless, there is a dearth of research that examines the nonlinear relationship between the ENR and urban green transformation. Taking the Yellow River Basin (YERB) as a case study, this paper uses a panel Tobit model to investigate the nonlinear impact of the ENR on urban green transformation efficiency (UGTE) and examines the mediating role of industrial agglomeration (AGG) and technological innovation (TEI). The findings demonstrate an inverted U-shaped nonlinear influence of the ENR on UGTE in the YERB. There is significant heterogeneity in the influence of the ENR on UGTE in the YERB. The influence of ENR on the UGTE shows a negative effect in the upper reaches, but it is nonlinear in the middle and lower reaches. The influence of ENR on UGTE of non-resource-based cities is negative, while the influence on UGTE of resource-based cities is nonlinear. Furthermore, ENR can improve UGTE in the YRB through TEI, but there is a threshold effect in this process.

**Keywords:** Environmental regulation; Urban green transformation; Nonlinear effect; Yellow River Basin; China

## 1. Introduction

As the basic administrative unit that constitutes a country and region, cities are important places for promoting human social progress and achieving sustainable development of the country and region [1]. With the large-scale advancement of global urbanization, problems such as excessive energy consumption, intensified pollution emissions, increasing resource shortages, and severe wealth inequality seriously hinder the sustainable development of world cities and regions [2], which is not good for the realization of global sustainable development goals [3]. How to realize urban green transformation? This has become a momentous link in promoting sustainable urban and regional development.

In the 1970s, the term “green development” was proposed in the environmental movement [4]. The OECD points out that green development is a sustainable development model that can provide permanent resources and a good living environment for human beings, while also promoting economic growth [5]. In China, “Green development” has been officially put forward as one of the five development

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

concepts [6]. Moreover, the Chinese government has also implemented some green development strategies and targets, such as the Green Transformation Strategy Outlook 2020-2050 [7]. Green transformation aims to transform traditional economy to low-carbon economy, and ultimately realizes urban sustainable development through continuous optimization and coordination of the relation among economic growth, energy resources with ecological environment [8-9]. At present, the green development level of Chinese cities is generally low at present, and it is urgent to promote green urban transformation [10].

The Chinese government is increasingly focusing on reducing the scale of pollution emissions and improving pollution control efficiency so as to promote urban green and sustainable development. The ENR is a series of regulatory means implemented by local governments to improve urban environmental quality [11]. The ENR can fully reflect the role of local governments in environmental supervision of enterprises, so as to form effective intervention in pollution emission of enterprises [12]. The Chinese government has also implemented some ENR measures to improve urban environmental quality, such as increasing pollution penalties, shutting down heavily polluting enterprises, and promoting carbon emissions trading [13-15]. Furthermore, scholars have carried out some studies on the correlation among the ENR and carbon emissions, but the research conclusions have not reached a consensus. Some scholars believe that the ENR can force enterprises to reduce pollution emissions through innovative pollution treatment technologies, thus promoting the reduction of urban carbon emissions [16-18]. Some other scholars believe that the ENR can increase production costs of enterprises, squeeze innovation and research and development funds, which is not conducive to enterprise production and emission reduction technology upgrading, and thus lead to the increase of urban pollution emissions [19-20]. In addition, other scholars have found a non-linear correlation among the ENR and carbon emissions, and different levels of ENR intensity may lead to distinct carbon reduction effects [21-22].

In the context of the green development concept, urban green transformation should not only achieve urban pollution and carbon reduction, but also pay attention to the coordinated development between urban economic growth, society, TEI and environment. However, there are few studies that incorporate innovative elements into the comprehensive evaluation system of urban green transformation, and scholars have paid insufficient attention to the nonlinear impact of ENR on UGTE. Therefore, this paper takes the YERB, a typical area where the Chinese government vigorously

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

promotes high-quality development, as a case area. This study established a theoretical framework for the impact of ENR on urban green transformation, and based on this, examined the nonlinear effects and mediating transmission mechanisms of ENR on UGTE.

The contributions of this paper are as follows: (1) Considering the significant impact of technological innovation on the green transformation of cities, this study incorporates innovation elements into the comprehensive evaluation system of urban green transformation, further enriching the comprehensive evaluation index system of urban green transformation. (2) The theoretical framework of the relationship between the ENR and UGTE is established, which enriches the theoretical research on ENR and urban green transformation. (3) We focus on the nonlinear effects of the ENR on UGTE and explore the mediating transmission mechanism between the two. This provides empirical evidence for identifying the key mechanisms driving regional urban green transformation. (4) We select the YERB as the case area, which can provide decision-making basis for policy makers to promote the green development in the YERB, and can also provide a basis for the green transformation of other major river basins (mainly focused on heavy industry development) in the world.

## 2. Theoretical analysis and hypotheses

### 2.1. ENR and urban green transformation

After the concept of green development and the dual carbon goals were proposed, many industries and social sectors in China have increasingly focused on urban green and sustainable development. Especially, after the Chinese government incorporated ecological environment indicators into local government performance evaluations, the ENR play a crucial role in promoting corporate pollution discharge reduction, as well as advancing urban ecological environment protection [23]. In recent years, the impact of the ENR on urban green transformation has gradually attracted the attention of scholars. Firstly, some scholars support Porter's hypothesis, believing that moderate ENR can force companies to eliminate outdated production processes, promote the upgrading of urban industrial structure, increase urban economic output and reduce pollution emissions, thereby driving urban green transformation [24-25]. Secondly, some scholars believe that ENR will increase the production and operation costs and pollution control costs of enterprises, squeeze technology research and development investment, hinder enterprise TEI and upgrading, lead to a decline in enterprise economic benefits, and thus hinder urban green transformation [26-27]. Thirdly, other scholars have revealed that there exists a nonlinear connection among the ENR and

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

urban green transformation, and the different ENR intensities will lead to different urban green transformation effects [28-29].

The natural environment in the YERB is relatively fragile, heavy chemical enterprises are widely distributed, and traditional industries play an crucial role in promoting urban economic growth and improving residents' living standards [30]. Appropriate ENR by local governments can promote the green transformation of production mode of enterprises, reduce urban industrial pollution emissions, and promote green urban development in the YERB. However, excessive ENR by local governments can improve the urban ecological environment to a certain extent, but it is also likely to lead to a decline in the vitality of enterprise innovation, resulting in a decline in economic benefits of enterprises and an increase in urban unemployment, thus hindering the green transformation of cities [31]. Moreover, there are great regional distinctions in the natural background, economic foundation and industrial structure of the YERB, and there are also great differences in the environmental supervision of enterprises by local governments [32]. Therefore, there may be significant regional distinctions in the influence of the ENR on UGTE. In addition, the impact of the ENR on UGTE may also be different in resource-based and non-resource-based cities. Therefore, we propose hypothesis 1 and hypothesis 2.

**H1.** There exists a nonlinear relationship between the ENR and UGTE in the YERB.

**H2.** The impact of the ENR on UGTE in the YERB is characterized by regional heterogeneity and urban type heterogeneity.

2.2. ENR, TEI and urban green transformation

The innovation compensation theory suggests that appropriate ENR can incentivize enterprises to engage in TEI, improve their production efficiency and pollution treatment efficiency, achieve economic benefits and reduce pollution emissions, thereby promoting urban green transformation [33-34]. Nevertheless, the influence of TEI on urban green transformation may be phased. When technical innovation is just getting started, enterprises need to invest a great quantity of funds in the purchase of advanced production equipment and the introduction of high-tech talents, which will cause an increase in production costs for enterprises, and the research and development of TEI achievements requires a certain amount of time investment. Therefore, in the short run, it may cause a decline in the economic benefits of enterprises, thereby hindering the urban green transformation [35]. When TEI achievements are successfully developed and applied to enterprise production, they can

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

greatly improve the production and emission reduction efficiency of enterprises, increase economic benefits and reduce pollution emissions, thereby promoting urban green transformation [36]. We propose hypothesis 3.

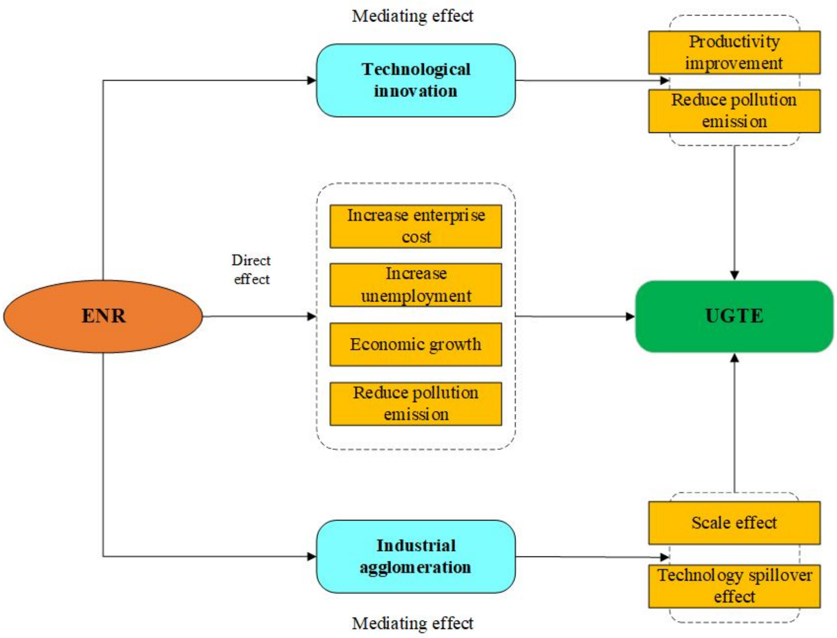
**H3.** The ENR can drive urban green transformation through TEI, but there is a certain threshold effect.

2.3. ENR, AGG and urban green transformation

Scholars have carried out a series of discussions on the relationship between the ENR and AGG. Some scholars found through research that the ENR could not affect regional industrial agglomeration [37], which was inconsistent with the "pollution refuge hypothesis" [38]. However, more scholars believe that appropriate ENR can guide AGG [39-40]. When the ENR promotes the enterprise innovation upgrade, the innovation compensation effect is formed. When the innovation compensation is higher than the input cost, the economic and environmental benefits of enterprises will be greatly improved, which will attract more enterprises to migrate to regions with stricter ENR and form industrial clusters [41]. AGG will form scale economies through scale effect and promote the increase of enterprise output value. Meanwhile, AGG will promote the optimization of enterprise production and pollution treatment technology through technology spillover effect [42], achieve urban economic growth and reduce pollution emission, and thus promote urban green transformation. We propose hypothesis 4.

**H4.** The ENR can drive urban green transformation through AGG.

Based on the above theoretical analysis, we established a theoretical relationship framework between ENR and UGTE, as depicted in Fig 1.



This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

**Fig 1.** A framework of the relationship among ENR and UGTE.

## 3. Research establishment and data sources

### 3.1. Study area

The YERB is rich in energy and mineral resources and is known as the "Energy Basin". Furthermore, the YERB is also an important industrial development zone and grain production base in China. Under the influence of the reform and opening-up policy, the economy of the coastal areas in eastern China and the Yangtze River Basin has developed rapidly, while the YERB is currently characterized by weak economic foundation, heavy industrial structure, and slow development of emerging industries due to the limitations of natural location conditions and national policies [43]. Under the major national strategic background of ecological protection and high-quality development in the YREB, the region urgently needs to achieve high-quality and sustainable development of the basin through urban green transformation. Based on this, we selected 79 cities in the YERB as research samples and explored the nonlinear effects of ENR on urban green transformation. Refer to relevant research [30,44], and taking into account the current development status of various provinces (autonomous regions) in the YERB, we divide it into the upper (UPP), middle (MID) and lower (LOW) reaches (Fig 2).

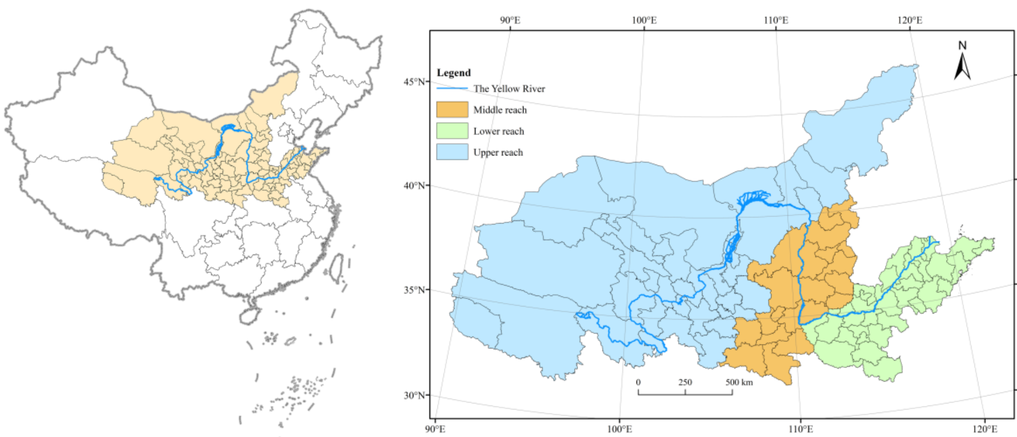



**Fig 2.** The study area.

### 3.2. Methods

#### 3.2.1. Super-efficiency SBM model

Charnes et al. (1978) proposed a data envelopment analysis (DEA), is an effective way to estimate the efficiency of input and output. However, it doesn't take account of the slack of input and output indicators [45]. Tone (2001) established a non-radial SBM model to address the issue of possible slack in variables [46]. However, both traditional DEA and SBM models are unable to effectively distinguish multiple efficiency values

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

with effective DMUs of 1. Tone (2002) once again proposed a Super-efficiency SBM model [47], which not only solved the problem of slack of variables, but also realized that the efficiency evaluation value＞1. Hence, we use this model to evaluate UGTE in the YERB. The model is expressed as follows:

$$UGTE = \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1-\frac{1}{s}\sum_{r=1}^{s}\frac{s_r^+}{y_{r0}}} \tag{1}$$

$$S.T.\begin{cases}\sum_{j=1,j\neq 0}^{n} x_{ij}\beta_j - s_i^- \le x_{i0}(i=1,2,\cdots,m)\\ \sum_{j=1,j\neq 0}^{n} y_{rj}\beta_j + s_i^+ \ge y_{r0}(r=1,2,\cdots,s)\\ \sum_{j=1}^{n}\beta_j = 1;\beta_j \ge 0;\beta,s^-,s^+\ge 0\end{cases} \tag{2}$$

where $\beta$ refers to the weight vector coefficients; $x_{i0}$ and $y_{r0}$ refer to input indicator and output indicator, respectively; $m$ and $s$ refer to the number of input indicators and output indicators, respectively; and $s_i^-$ and $s_r^+$ both refer to relaxation variables.

3.2.2. Panel Tobit model

Tobin (1958) proposed a Tobit model, is mainly used to solve the model regression problem when the dependent variable is limited [48]. The minimum value of the UGTE is 0. Hence, We use this model to assess the influence of the ENR on UGTE in the YERB. The model is depicted as follows:

$$UGTE_{it} = \beta_0 + \beta_1 X_{1it} + \beta_2 X_{2it} + \cdots + \beta_j X_{jit} + \varepsilon_{it} \tag{3}$$

Where $UGTE_{it}$ represents the UGTE of city $i$ in the year $t$; $X_{jit}$ refers to explaining variables; $\beta_0$ is the intercept term; $\beta_j$ is the regression parameter; $\varepsilon_{it}$ refers to the random error.

3.2.3. Panel termediary model

Baron and Kenny (1986) proposed a termediary model [49], based on which we constructed a panel termediary-effect model to explore whether TEI and AGG have an intermediary role among the ENR with UGTE. The model is depicted as follows:

$$UGTE = cTEI / AGG + \alpha_1 \tag{4}$$

$$TEI / AGG = aENR + \alpha_2 \tag{5}$$

$$UGTE = c'ENR + bTEI / AGG + \alpha_3 \tag{6}$$

Where $a$, $b$, $c$ and $c$' are all regression coefficients. $\alpha_1$, $\alpha_2$ and $\alpha_3$ represent random error terms.

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

#### 3.2.4. A panel threshold model

In order to investigate whether TEI and AGG have a threshold value among the ENR with UGTE, the threshold effect model proposed by Hansen (1999) is used in this paper to explore the intermediary transmission effect among TEI and AGG [50]. The model is expressed as follows:

$$\begin{aligned} UGTE_{it} = {} & \beta_0 + \beta_1 \ln ENR_{it} \cdot I(\ln TEI_{it} \le \gamma_1) + \beta_2 \ln ENR_{it} \cdot I(\ln TEI_{it} > \gamma_1) \\ & + \beta_j \ln X_{it} + \mu_i + \varepsilon_{it} \end{aligned} \tag{7}$$

Where I() represents the indicator function; $X_{it}$ is the control variable; $\beta$ is the influence coefficient; $\gamma$ is the threshold value; $\mu_i$ represents the individual fixed effect.

The panel double threshold model is expressed as follows:

$$\begin{aligned} UGTE_{it} = {} & \beta_0 + \beta_1 \ln ENR_{it} \cdot I(\ln TEI_{it} \le \gamma_1) + \beta_2 \ln ENR_{it} \cdot I(\gamma_1 < \ln TEI_{it} \le \gamma_2) \\ & + \beta_3 \ln ENR_{it} \cdot I(\ln TEI_{it} > \gamma_2) + \beta_j \ln X_{it} + \mu_i + \varepsilon_{it} \end{aligned} \tag{8}$$

### 3.3. Variables

#### 3.3.1. Dependent variable

UGTE is selected as the dependent variable. The input indicators include capital, labor, technology, energy and land. The expected output indicators mainly include economic, social, ecology and innovation. The unexpected output indicator is the scale of carbon emission. The specific indicators and their meanings are depicted in Table 1.

**Table 1.** Evaluation index system of UGTE.

| Indicator types | Dimensions | Indicator layer |
|---|---|---|
| Input | Capital | Investment in fixed assets/billion yuan |
| | Labour force | Number of employees at the end of the year/10000 person |
| | Technology | Technology financial expenditure/10000 yuan |
| | Energy | Electricity consumption/10000 KWH |
| | Land | The construction land area of the municipal district/km$^2$ |
| Expected output | Economy | GDP/billion yuan; The proportion of tertiary industry/% |
| | Society | Employees' average wage/yuan |
| | ecology | Green rate of built-up area/% |
| | Innovation | Number of patents granted/PCS |
| Unexpected output | Environment | Urban carbon dioxide emissions/tons |

#### 3.3.2. Explanatory variables

The ENR was selected as the explanatory variable to investigate the impact of the ENR on UGTE in the YERB. The treatment rate of urban industrial wastewater, the removal rate of industrial $SO_2$ and the utilization rate of general industrial solid waste

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

were selected as specific indicators, and the ENR was calculated by entropy weight method [51].

### 3.3.3. Intermediary variables and threshold variables

TEI and AGG are selected as intermediary variables to investigate whether they can play an intermediary role among the ENR and UGTE. The number of patents granted is used to characterize the level of TEI [36]. AGG is mainly characterized by the agglomeration degree of urban secondary and tertiary industries, which is specifically obtained by location entropy method. Furthermore, TEI and AGG are also selected as threshold variables to investigate their threshold effects.

### 3.3.4. Control variables

The process of urban green transformation may also be influenced by other factors. We screened some indicators as control variables.

Industrial structure upgrading (INS). The INS can promote urban economic growth, increase residents' income level and reduce pollution emissions, which can promote the urban green transformation. Moreover, the process of industrial restructuring may cause discomfort in urban industrial transformation, leading to a short-term decline in GDP, and thus hindering urban green transformation. Refer to relevant research [52], this paper calculates INS by the following method: value-added of primary industry×1 + value-added of secondary industry×2 + value-added of tertiary industry×3.

Degree of openness to the outside world (OPW). OPW is beneficial to attracting foreign-funded enterprises, creating more jobs, driving urban economic growth, and promoting urban green transformation. According to relevant literature [53-54], total imports and exports as a share of GDP is used to characterize OPW.

Urbanization rate (URB). Improving URB can promote population agglomeration and industrial scale expansion, lead to increased urban pollution, and thus hinder urban green transformation. The proportion of urban population in the total urban population is used to characterize URB [55].

Degree of government intervention (GOI). Under the fiscal decentralization system in China, local governments guide and intervene in the development and utilization of land resources, as well as the planning and construction of public service facilities, through fiscal expenditures. Appropriate intervention measures by local governments can stimulate urban economic growth and ecological environment construction, thereby promoting urban green transformation. Refer to relevant research [56], we select the proportion of local fiscal expenditure in GDP to represent GOI.

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

Transportation accessibility (TRA). Higher urban TRA can reduce transportation costs and time costs, promote the flow of capital, labor and technology factors, help promote urban industrial development and economic growth, and thus promote urban green transformation. Moreover, higher TRA may accelerate the outflow of local high-quality labor, which is not conducive to urban industrial TEI, and thus hinder the urban green transformation. Refer to relevant research [57-58], the mileage of highways open to traffic is used to characterize TRA.

Agglomeration of secondary industries (SIA). SIA can increase employment opportunities, improve residents' income level and promote urban economic growth, thus promoting urban green transformation. Furthermore, SIA may lead to an increase in urban pollution discharge, thereby hindering urban green transformation. SIA is characterized by calculating the location entropy of the added value of the urban secondary industry [59].

Agglomeration of tertiary industries (TIA). The tertiary industry is mainly high-tech industry and modern service industry. TIA is beneficial to the optimization of urban industrial structure and the reduction of energy consumption, so as to promote urban green transformation. TIA is characterized by calculating the location entropy of the added value of the tertiary industry.

The statistical results of variable data are depicted in Table 2. Furthermore, we attempted to eliminate the influence of heteroscedasticity on the results, and thus logarithmic processing was performed on all variables.

**Table 2.** Statistical results of variables.

| Variables | $N$ | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| *lnUGTE* | 1264 | 0.6831 | 0.3900 | 0.0515 | 1.8676 |
| *lnENR* | 1264 | -2.4384 | 1.7251 | -6.8867 | 2.3355 |
| *lnINS* | 1264 | 7.8450 | 1.0220 | 4.8669 | 10.3732 |
| *lnOPW* | 1264 | 12.9710 | 2.2146 | 3.2011 | 17.9772 |
| *lnURB* | 1264 | 3.9119 | 0.3031 | 2.5440 | 4.5723 |
| *lnGOI* | 1264 | -1.7238 | 0.5640 | -3.1554 | 1.1383 |
| *lnTRA* | 1264 | 9.2864 | 0.7167 | 5.7557 | 10.5959 |
| *lnSIA* | 1264 | -0.0342 | 0.2478 | -0.9836 | 0.4628 |
| *lnTIA* | 1264 | -0.0803 | 0.2385 | -1.0376 | 0.5066 |
| *lnTEI* | 1264 | 5.2631 | 2.4336 | 0 | 10.9629 |
| *lnAGG* | 1264 | -0.0310 | 0.0839 | -0.3418 | 0.0950 |

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

### 3.4. Data sources

The data used are mainly from China Urban Statistical Yearbook, and the annual statistical bulletins of provinces, municipalities and autonomous regions in the YERB. In 2008, the United Nations Environment Programme launched the Green Economy Initiative, encouraging countries to give priority to green investments in their economic stimulus plans. The green economy has gradually become a key focus of development. Therefore, the research period chosen for this paper is from 2008 to 2023. The missing data in certain years were filled in using interpolation. Moreover, we use the GDP price in 2008 as the constant price and adjust the prices of relevant economic indicators accordingly.

## 4. Results

### 4.1. Benchmark regression

We empirically examine the impact of the ENR on UGTE in the YERB by constructing a panel Tobit model. As shown in Table 3, the influence coefficient of the ENR on UGTE in the YERB is 0.0221, and passed the significance test. The impact coefficient of the $ENR^2$ on UGTE is -0.0159, and passed the significance test. This indicates that the influence of the ENR on UGTE in the YERB has a nonlinear effect, which verifies **H1**. Moderate ENR can promote green urban transformation in the YERB. However, when the intensity of ENR is too high, it will hinder green urban transformation in the YERB.

Moreover, industrial structure and transportation accessibility have a significant negative effect on UGTE in the YERB, indicating that industrial structure and transportation accessibility may hinder urban green transformation in the YERB. Government intervention, secondary industry agglomeration and tertiary industry agglomeration all have significant positive effects on UGTE. The influence of OPW and urbanization rate on UGTE is not significant, which may due to the overall low OPW in the YERB, and the lack of significant promotion effect on urban green transformation. Improving urbanization rate may lead to an increase in urban pollution discharge, which is not beneficial to urban green transformation.

**Table 3.** Benchmark regression.

| Variables | Coef. | Std.Err. | *Z* | *P* |
|---|---|---|---|---|
| *lnENR* | 0.0221 | 0.0113 | 1.95 | 0.052 |
| *lnENR*$^2$ | -0.0159 | 0.0130 | -2.09 | 0.040 |
| *lnINS* | -0.1012 | 0.0381 | -2.66 | 0.008 |
| *lnOPW* | 0.0021 | 0.0128 | 0.16 | 0.871 |
| *lnURB* | 0.1414 | 0.1068 | 1.32 | 0.185 |

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

| | | | | |
|---|---|---|---|---|
| *lnGOI* | 0.2243 | 0.0459 | 4.89 | 0.000 |
| *lnTRA* | -0.0702 | 0.0421 | -1.67 | 0.096 |
| *lnSIA* | 0.3725 | 0.1424 | 2.62 | 0.009 |
| *lnTIA* | 0.2546 | 0.1261 | 2.02 | 0.043 |
| Cons | 1.9165 | 0.5442 | 3.52 | 0.000 |

## 4.2. Heterogeneity analysis

We analyzed regional heterogeneity and urban type heterogeneity in the YERB (Table 4). There are obvious regional distinctions in the influence of the ENR and ENR$^2$ on UGTE in UPP, MID and LOW, which verifies **H2**. Concretely, the influence coefficient of the ENR on UGTE in the UPP is negative, while the impact coefficient of the ENR$^2$ on UGTE in the UPP is positive but has not passed the significance test, revealing that increasing the intensity of ENR will hinder the urban green transformation in the UPP. The influence coefficients of the ENR on UGTE in the MID and LOW are 0.0074 and 0.0092, respectively. The influence coefficients of the ENR$^2$ on UGTE in the MID and LOW are -0.0125 and -0.0068, respectively, indicating that there is an inverted U-shaped nonlinear effect of the ENR on UGTE in the MID and LOW.

The results of the heterogeneity test of urban types are depicted in Table 4. There is heterogeneity in the impact of the ENR and ENR$^2$ on UGTE of resource-based (RBC) and non-resource-based cities (NRBC) in the YERB, which verifies **H2**. Specifically, the influence coefficient of the ENR on UGTE in RBC is positive, while the influence coefficient of the ENR$^2$ on UGTE in RBC is negative, which reveals that the influence of the ENR on UGTE in RBC has a nonlinear effect. The influence coefficient of the ENR on UGTE in NRBC is negative, while the influence coefficient of the ENR$^2$ on UGTE in NRBC is also negative but has not passed the significance test, which indicates that the ENR can hinder the green transformation of NRBC in the YERB.

**Table 4.** Heterogeneity test.

| Variables | UPP | MID | LOW | RBC | NRBC |
|---|---|---|---|---|---|
| *lnENR* | -0.0264** | 0.0074* | 0.0092*** | 0.0114** | -0.0155* |
| *lnENR*$^2$ | 0.0027 | -0.0125** | -0.0068** | -0.0058* | -0.0036 |
| *lnINS* | -0.2486*** | -0.0991 | -0.2376*** | -0.3017*** | -0.0870 |
| *lnOPW* | -0.0248 | 0.0260 | 0.0702** | -0.0171 | 0.0089 |
| *lnURB* | -0.0037 | -0.1374* | 0.3490 | 0.0709 | 0.1090 |
| *lnGOI* | 0.0303* | 0.1145 | -0.0777** | 0.1486* | 0.1724** |
| *lnTRA* | -0.0463 | -0.2254 | 0.0481 | 0.0285 | -0.0889 |
| *lnSIA* | 0.1933 | 0.8033** | -0.3620 | 0.4376*** | 0.2931 |
| *lnTIA* | 0.1173 | 0.2321 | 0.3550* | 0.0200 | 0.4234** |
| Cons | 3.2555*** | 3.8326** | -0.9198** | 2.6398*** | 1.8849** |

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

Notes: *, **, and, ***refer to the 10%, 5%, and 1% significance levels, respectively. The same as in the following tables.

### 4.3. Endogeneity and robustness test

In order to evaluate whether the model has endogeneity problems, we select air flow coefficient as the instrumental variable. Firstly, the air flow coefficient is related to the ENR intensity. The stronger the air flow in the region, the more conducive to the diffusion of pollutants, resulting in a relatively low ENR intensity in the region, meeting the correlation requirements of instrumental variable. Secondly, the calculation of air flow coefficient involves wind speed and atmospheric layer height, which are mainly influenced by natural phenomena such as meteorological systems and geographical conditions, meeting the exogeneity requirements of instrumental variable. Therefore, we select the air flow coefficient as the instrumental variable and apply the two-stage least square method (2SLS) to perform the endogeneity test (Table 5). The results depict that there are no weak instrumental variables, and both the ENR and the instrumental variable have significant impact coefficients on UGTE in the YERB, revealing that there is no severe endogeneity in the initial model.

**Table 5.** Endogeneity test.

| Variables | First stage | Second stage |
|---|---|---|
| ENR | — | 0.1164** |
| Instrumental variable | 0.4799** | — |
| Control variables | YES | YES |
| Cons | -4.8161* | 1.3121*** |
| F test | 15.86*** | — |
| LM statistic | 19.620*** | — |
| F value | 23.020*** | — |
| R-squared | 0.3593 | 0.4127 |

Furthermore, we carried out model regression by changing the number of control variables, replacing the calculation method of control variables and eliminating special samples. The specific test methods are as follows: Delete the control variable of OPW (1), replace the calculation method of government intervention with urban per capita fiscal expenditure as a proportion of urban, provincial and national per capita fiscal expenditure (2), and exclude provincial capital and sub-provincial cities (3). The model regression results are basically in line with the initial model (Table 6). Hence, the initial model results have strong robustness.

**Table 6.** Robustness test.

| Variables | (1) | (2) | (3) |
|---|---|---|---|
| *lnENR* | 0.0193** | 0.0110* | 0.0212** |

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

| | | | |
|---|---|---|---|
| *lnENR*$^2$ | -0.0120** | -0.0098* | -0.0148*** |
| *lnINS* | -0.1876 | -0.2403*** | -0.2247*** |
| *lnOPW* | — | -0.0067 | -0.0070 |
| *lnURB* | 0.0494 | -0.1087 | 0.0940 |
| *lnGOI* | 0.1404*** | 0.3242*** | 0.1583*** |
| *lnTRA* | -0.0526 | -0.0334 | -0.0476 |
| *lnSIA* | 0.3782*** | 0.2629* | 0.3727*** |
| *lnTIA* | 0.2567** | 0.2109* | 0.1461 |
| Cons | 2.4851*** | 3.5113*** | 2.666*** |

### 4.4. Further analysis

#### 4.4.1. Mediation effect analysis

We use the step-up regression method to test whether TEI and AGG have intermediary effects in the process of the ENR affecting UGTE (Table 7). The influence coefficient of the ENR on TEI is 0.0187. When TEI is added, the influence coefficient of the ENR on UGTE is 0.0218, while the impact coefficient of TEI on UGTE is 0.1850. The results depict that TEI has a significant positive intermediary effect in the process of ENR affecting UGTE. The impact coefficient of the ENR$^2$ on UGTE is -0.0079. When TEI is added, the impact coefficient of the ENR$^2$ on UGTE is -0.0147, while the impact coefficient of TEI on UGTE is significantly positive. This reveals that TEI has a significant negative intermediary effect in the process of ENR$^2$ on UGTE. In addition, the test results reveal that AGG has no intermediary effect between the ENR and UGTE, which contradicts **H4**. This may be attributed to the ineffective utilization of the scale effect of AGG in the YERB.

**Table 7.** Mediation effect test.

| Variables | TEI | UGTE | TEI | UGTE | AGG | UGTE | AGG | UGTE |
|---|---|---|---|---|---|---|---|---|
| *lnENR* | 0.0187** | 0.0218* | | | 0.0098* | 0.0198* | | |
| *lnENR*$^2$ | | | -0.0079* | -0.0147* | | | 0.0036* | -0.0125 |
| *lnTEI* | | 0.1850*** | | 0.0968** | | | | |
| *lnAGG* | | | | | | 0.0025 | | 0.0048 |
| Control | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Cons | -4.8595** | 2.4860*** | 0.6579*** | -2.3951*** | -5.0052*** | 2.6370*** | -6.5318 | -2.6071*** |
| Bootstrap test | [-0.063, -0.013] | | [-0.052, -0.010] | | [-0.0123, -0.0261] | | [-0.0086, -0.0189] | |
| *N* | 948 | | 948 | | 948 | | 948 | |

#### 4.4.2. Threshold effect analysis

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

The threshold interval test results of TEI are depicted in Table 8. The single threshold value of TEI is significant, while other values are not. Moreover, the likelihood ratio test results are in line with the test results (Fig 3). Therefore, TEI can play a single-threshold role among the ENR and UGTE in the YERB, with a threshold value of 8.14.

**Table 8.** Threshold effect test of TEI.

| Model | Threshold value | F value | P value | Critical value 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| Single-threshold | 8.1400 | 19.94 | 0.0367 | 28.1534 | 18.9692 | 14.4159 |
| Double-threshold | 9.3500 | 3.79 | 0.7900 | 19.2481 | 15.1279 | 13.5221 |
| Triple-threshold | 11.2500 | 11.11 | 0.2867 | 39.7743 | 26.9573 | 19.3454 |

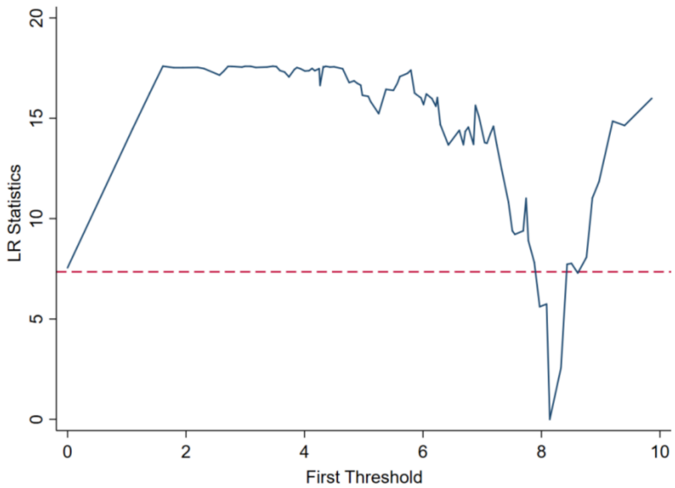



**Fig 3.** Likelihood ratio test.

The results of the single-threshold effect of TEI are depicted in Table 9. Specifically, when TEI is ≤ 8.14, the impact coefficient of the ENR on UGTE is −0.0185. When TEI exceeds 8.14, the impact coefficient of the ENR on UGTE is 0.0721. This reveals that the ENR can drive urban green transformation in the YERB through TEI, but there is a certain threshold effect. When urban TEI＞8.14, the ENR can promote urban green transformation through TEI, which confirms **H3**.

**Table 9.** Results of threshold effect of TEI.

| Variables | Coef. | Std.Err. | t | P |
|---|---|---|---|---|
| $lnENR(lnTEI \leq 8.14)$ | -0.0185 | 0.0186 | -1.99 | 0.023 |
| $lnENR(lnTEI > 8.14)$ | 0.0721 | 0.0264 | 2.73 | 0.008 |
| *lnINS* | -0.0635 | 0.0478 | -1.33 | 0.188 |
| *lnOPW* | 0.0133 | 0.0204 | 0.65 | 0.517 |
| *lnURB* | 0.0036 | 0.1601 | 0.02 | 0.982 |
| *lnGOI* | 0.0454 | 0.0678 | 0.67 | 0.505 |
| *lnTRA* | 0.0478 | 0.0489 | 0.98 | 0.333 |
| *lnSIA* | 0.5969 | 0.3344 | 1.78 | 0.078 |

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

| | | | | |
|---|---|---|---|---|
| *lnTIA* | 0.5156 | 0.2723 | 1.89 | 0.062 |
| Cons | 0.6266 | 0.9210 | 0.68 | 0.498 |

# 5. Discussion

## 5.1. Impact of the ENR on UGTE

In this paper, we examined the impact of the ENR and $ENR^2$ on UGTE in the YERB by constructing a panel Tobit model. We found that the influence of the ENR on UGTE in the YERB exhibits an inverted U-shaped nonlinear effect, and the influence effect has significant heterogeneity, which is in accordance with the conclusions of some scholars [28-29]. Local governments can promote urban green transformation in the YERB, especially in the MID and LOW, by implementing moderate ENR intensity; In UPP, ENR can hinder urban green transformation. This may be attributed to the widespread distribution of ecological protection areas in UPP such as Qinghai, Gansu, and Inner Mongolia. Local governments often implement stricter ENR to ensure regional ecological security. However, although strict ENR can reduce urban pollution emissions, they squeeze the innovation and development vitality of enterprises, which is bad for their industrial transformation, and thus hinders the green transformation of regional cities [31]. The economic foundation and industrial development in the MID and LOW of the YERB are sound. Since the dual-carbon goal was proposed, local governments have concentrated on the coordinated development of industrial adjustment and ecological protection. For example, after vigorously implementing the transformation of old and new driving forces in Shandong, the regional natural environment has been significantly improved. The new driving force dominated by high-tech industries effectively promoted the development of regional low-carbon economy [30]. Moreover, local governments attend to the reasonable guidance of enterprise production methods in promoting the transformation of old and new driving forces, and adopt moderate ENR intensity to guide enterprise production methods to upgrade towards intelligence and green, thereby promoting the green transformation of regional cities.

## 5.2. The intermediary effect of TEI

TEI can play a positive mediating role among the ENR and UGTE, and a negative mediating role among the $ENR^2$ and UGTE (Fig 4), which is in accordance with the conclusion of Zhang et al. (2020) [60]. The excessive ENR will increase the production and operation costs of enterprises and reduce the investment in innovation and research and development of enterprises, which is not beneficial to the improvement and upgrading of production technology and pollution emission treatment technology of

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

enterprises, and thus hinder urban green transformation. However, when urban TEI develops to a certain level, the ENR can promote urban green transformation through TEI, which is basically in accordance with the conclusion of Du et al. (2021) [23]. In the early stage of TEI, the ENR may squeeze the innovation funds of enterprises and weaken the motivation for research. Furthermore, there is a certain time lag in the research and development and application of innovative achievements, which may lead to the slow or even stagnation of the production technology transformation of enterprises, and thus hinder urban green transformation. When innovation investment accumulates to a certain extent, TEI achievements are successfully developed and applied, greatly improving the production efficiency and emission reduction efficiency of enterprises, stimulating urban economic growth and the reduction of pollution discharge [30]. During this period, the appropriate ENR can further stimulate enterprises to carry out green technology innovation, accelerate the green and clean production of enterprises, and then facilitate the urban green transformation.

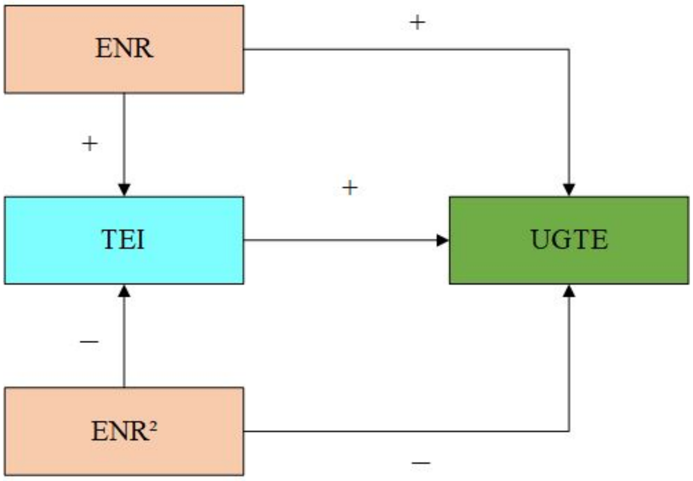



**Fig 4.** Impact path of the ENR on UGTE.

5.3. Limitations and prospects

We explored the nonlinear impact of the ENR on UGTE and the mediating transmission mechanism by constructing a panel Tobit model, which has certain innovation. However, this study may still have the following shortcomings: (1) the panel Tobit model does not consider the influence of spatial factors in the regression process, which may cause some bias to the research results. (2) We only estimate the influence of the ENR on UGTE in the YERB through statistical yearbook data, lacking practical basis for on-site investigation. In the future, we will use spatial econometric models that consider spatial factors to reveal the spatial spillover effects of the ENR on UGTE in the YERB. In addition, we will conduct on-site investigations in provinces along the YERB to further verify the research conclusions.

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

# 6. Conclusions and suggestions

## 6.1. Conclusions

Taking 79 cities in the YERB from 2008 to 2023 as empirical samples, this paper explores the nonlinear influence of the ENR on UGTE by constructing a baseline regression model, and examines the mediating effects of TEI and AGG.

Firstly, the influence of the ENR on UGTE in the YERB exhibits an inverted U-shaped effect of “promoting first, then inhibiting”. Moderate ENR can facilitate green urban transformation in the YERB, while excessive ENR will hinder green urban transformation. Moreover, Industrial structure and transportation accessibility have significant negative effects on UGTE in the YERB. Government intervention, secondary industry agglomeration and tertiary industry agglomeration have significant positive effects on UGTE in the YERB.

Secondly, there is heterogeneity in the influence of the ENR and $ENR^2$ on UGTE in the YERB. The ENR has a nonlinear effect on UGTE in the MID and LOW, while it has a negative effect on UGTE in the UPP. The ENR has a nonlinear effect on UGTE of RBC, and a negative effect on UGTE of NRBC. Furthermore, there are significant heterogeneity characteristics in the influence of control variables on UGTE.

Thirdly, TEI can play a positive mediating role among the ENR and UGTE, while it play a negative mediating role between the $ENR^2$ and UGTE. AGG has no intermediary effect between the ENR and UGTE. Moreover, TEI has a single threshold effect among the ENR and UGTE in the YERB, with a threshold value of 8.14. When the level of urban TEI＞8.14, the ENR can facilitate urban green transformation in the YERB through TEI.

## 6.2. policy suggestions

Firstly, for local governments, especially in the MID and LOW of the YERB, they should maintain moderate ENR intensity, reasonably guide enterprises to increase investment in TEI, improve the intelligence and green level of production technology and pollution treatment technology, and promote the improvement of production efficiency and emission reduction efficiency. Moreover, local governments should implement talent introduction policies to help enterprises broaden talent introduction channels, promote the optimization and upgrading of production technology and management experience of enterprises through the introduction of high-tech talents, accelerate urban industrial structure transformation, and then promote urban green transformation.

Secondly, for local enterprises, they should actively respond to the government’s

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

environmental regulatory policies, consciously improve their pollution emission treatment capabilities, and ensure that their pollution emission intensity meets local ENR standards. Furthermore, enterprises should continue to increase investment in green technology innovation, actively introduce high skilled innovative talents, continuously cultivate and strengthen the skilled talent team, cultivate independent research and development innovation capabilities, optimize production structure and management experience, enhance technology innovation capabilities, and promote the intelligent and green development of enterprises.

Finally, enterprises in the UPP, MID, and LOW of the YERB should strengthen industrial technology exchange and cooperation, continuously enhance their industrial technology innovation capabilities, promote the innovation and upgrading of production technology and emission reduction technology, form an industrial chain and innovation chain of the UPP, MID, and LOW, and jointly promote urban green transformation throughout the entire river basin region.

## Author Contributions

**Conceptualization**: Chengzhen Song.
**Data curation:** Chengzhen Song.
**Formal analysis:** Chengzhen Song.
**Methodology:** Chengzhen Song.
**Software:** Chengzhen Song.
**Investigation:** Chengzhen Song.
**Writing—original draft:** Chengzhen Song.
**Writing－review & editing:** Chengzhen Song.

## References

1. Liao B, Li L. Spatial division of labor, specialization of green technology innovation process and urban coordinated green development: Evidence from China. Sustainable Cities and Society. 2022; 80, 103778. https://doi.org/10.1016/j.scs.2022.103778
2. Du X, Zhou J, Xiao C. Spatial effects and influencing factors of urban sustainable development: An analysis of urban agglomerations in China. Economic Analysis and Policy. 2024; 81, 556-575. https://doi.org/10.1016/j.eap.2023.12.022
3. Biermann F, Hickmann T, Sénit C.-A, et al. Scientific evidence on the political impact of the Sustainable Development Goals. Nature Sustainability. 2022; 5, 795-800. https://doi.org/10.1038/s41893-022-00909-5
4. Kline B. First along the river: A brief history of the US environmental movement. New York: Rowman & Littlefield Publishers. 2011.
5. Hao F, Zang Y, Fan B, Zhang Y. Environmental regulation promotes green development in China: from the perspective of technological innovation. Frontiers in Energy Research. 2023; 11. https://doi.org/10.3389/fenrg.2023.1209650
6. Su R, Zheng T, Zhong Y, et al. Role of Digital Inclusive Finance for High-Quality Business Development: A Study of China's "Five Development Concept" Policy. Sustainability. 2023; 15, 12078.

This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

https://doi.org/10.3390/su151512078

7. Jia C, Shang M, Cao J, et al. Empirical analysis of the impact of the digital economy on the green transformation of manufacturing: Evidence from China. PLoS ONE. 2023; 18(8): e0289968. https://doi.org/10.1371/journal.pone.0289968
8. Wang H, Cui H, Zhao Q. Effect of green technology innovation on green total factor productivity in China: Evidence from spatial durbin model analysis. Journal of Cleaner Production. 2021; 288, 125624. https://doi.org/10.1016/j.jclepro.2020.125624
9. Zhuo C, Xie Y, Mao Y, et al. Can cross-regional environmental protection promote urban green development: Zero-sum game or win-win choice? Energy Economics. 2022; 106, 105803. https://doi.org/10.1016/j.eneco.2021.105803
10. Qiu S, Wang Z, Liu S. The policy outcomes of low-carbon city construction on urban green development: Evidence from a quasi-natural experiment conducted in China. Sustainable Cities and Society. 2021; 66, 102699. https://doi.org/https://doi.org/10.1016/j.scs.2020.102699
11. Goh E, Effendi S. Overview of an effective governance policy for mineral resource sustainability in Malaysia. Resources Policy. 2017; 52, 1-6. https://doi.org/10.1016/j.resourpol.2017.01.012
12. Yu G, Liu K. Foreign direct investment, environmental regulation and urban green development efficiency—An empirical study from China. Applied Economics. 2023; 56, 2738–2751. https://doi.org/https://doi.org/10.1080/00036846.2023.2200232
13. Stavropoulos S, Wall R, Xu Y. Environmental regulations and industrial competitiveness: Evidence from China. Applied Economics. 2018; 50, 1378–1394. https://doi.org/https://doi.org/10.1080/00036846.2017.1363858
14. Tang H, Liu J, Mao J, et al. The effects of emission trading system on corporate innovation and productivity-empirical evidence from China's SO2 emission trading system. Environmental Science and Pollution Research. 2020; 27, 21604-21620. https://doi.org/10.1007/s11356-020-08566-x
15. Zhang W, Luo Q, Liu S. Is government regulation a push for corporate environmental performance? Evidence from China. Econ. Anal. Policy. 2022; 74, 105-121.
16. He X, Zhang Y. The influencing factors of China's industrial carbon emissions and the recombination effect of CKC-An empirical study of dynamic panel data based on STIRPAT model. China Ind Econ. 2012; 1, 26-35.
17. Pan T, Zhang J, Wang Y, et al. The Impact of Environmental Regulations on Carbon Emissions of Chinese Enterprises and Their Resource Heterogeneity. Sustainability. 2024; 16, 1058. https://doi.org/10.3390/su16031058
18. Ren S, Li X, Yuan B, et al. The effects of three types of environmental regulation on eco-efficiency: A cross-region analysis in China. Journal of Cleaner Production. 2018; 173, 245-255. https://doi.org/10.1016/j.jclepro.2016.08.113
19. Sinn H.-W. Public policies against global warming: a supply side approach. International Tax and Public Finance. 2008; 15, 360-394. https://doi.org/10.1007/s10797-008-9082-z
20. Wang D, Li J. Environmental regulation, technological progress and energy carbon emission efficiency. Technol Econ Manage Res. 2022; 7, 31-36.
21. Zhang W, Li G, Uddin M.K, et al. Environmental regulation, Foreign investment behavior, and carbon emissions for 30 provinces in China. Journal of Cleaner Production. 2020; 248. https://doi.org/10.1016/j.jclepro.2019.119208
22. Zhang X, Fan D. Is multi-pronged better? Research on the driving effect of the combination of environmental regulation in mining cities. Journal of Cleaner Production. 2024; 436, 140689. https://doi.org/10.1016/j.jclepro.2024.140689
23. Du K, Cheng Y, Yao X. Environmental regulation, green technology innovation, and industrial structure upgrading: The road to the green transformation of Chinese cities. Energy Economics. 2021; 98, 105247. https://doi.org/10.1016/j.eneco.2021.105247
24. Ghosal V, Stephan A, Weiss J.F. Decentralized environmental regulations and plant-level productivity. Bus.

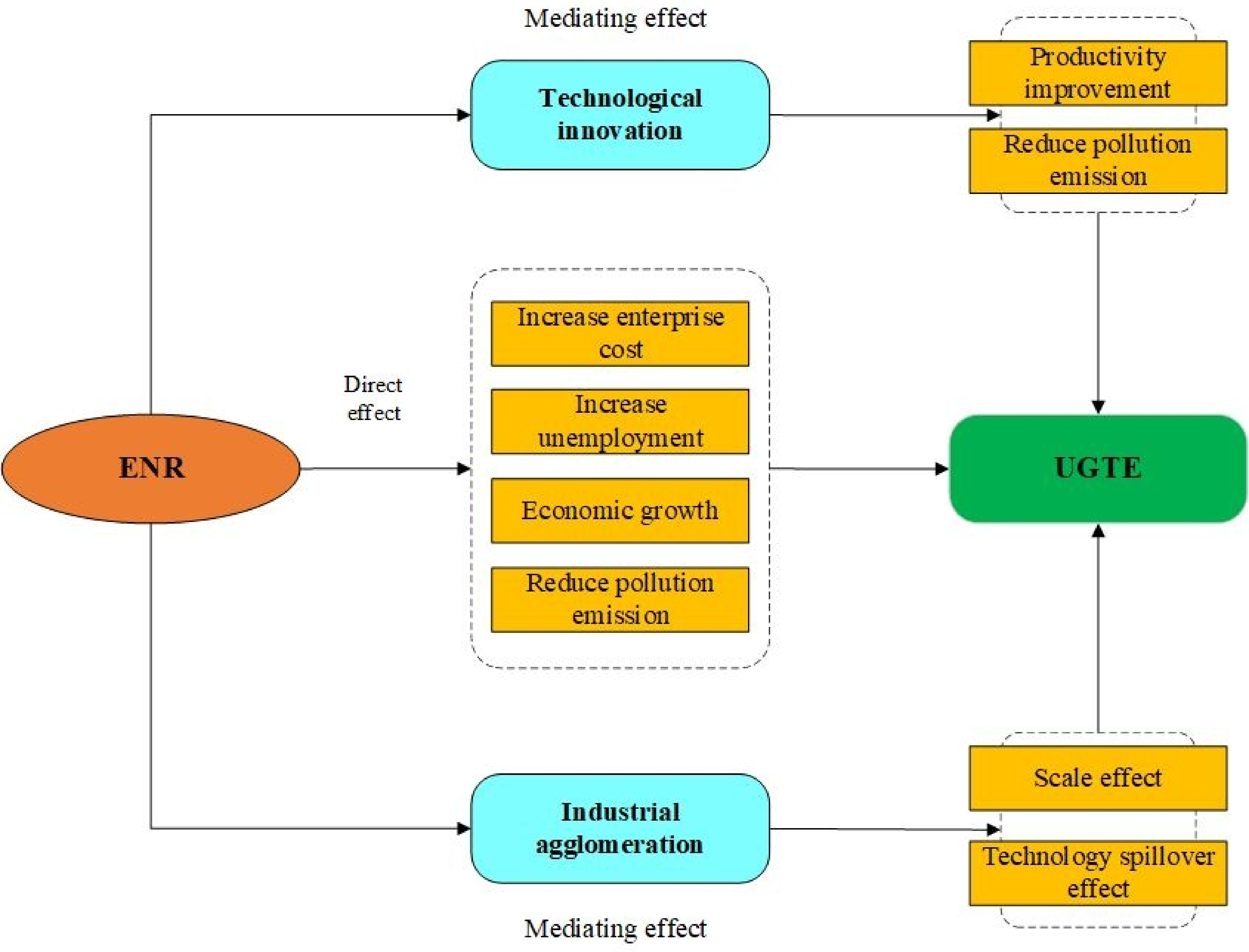
This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.

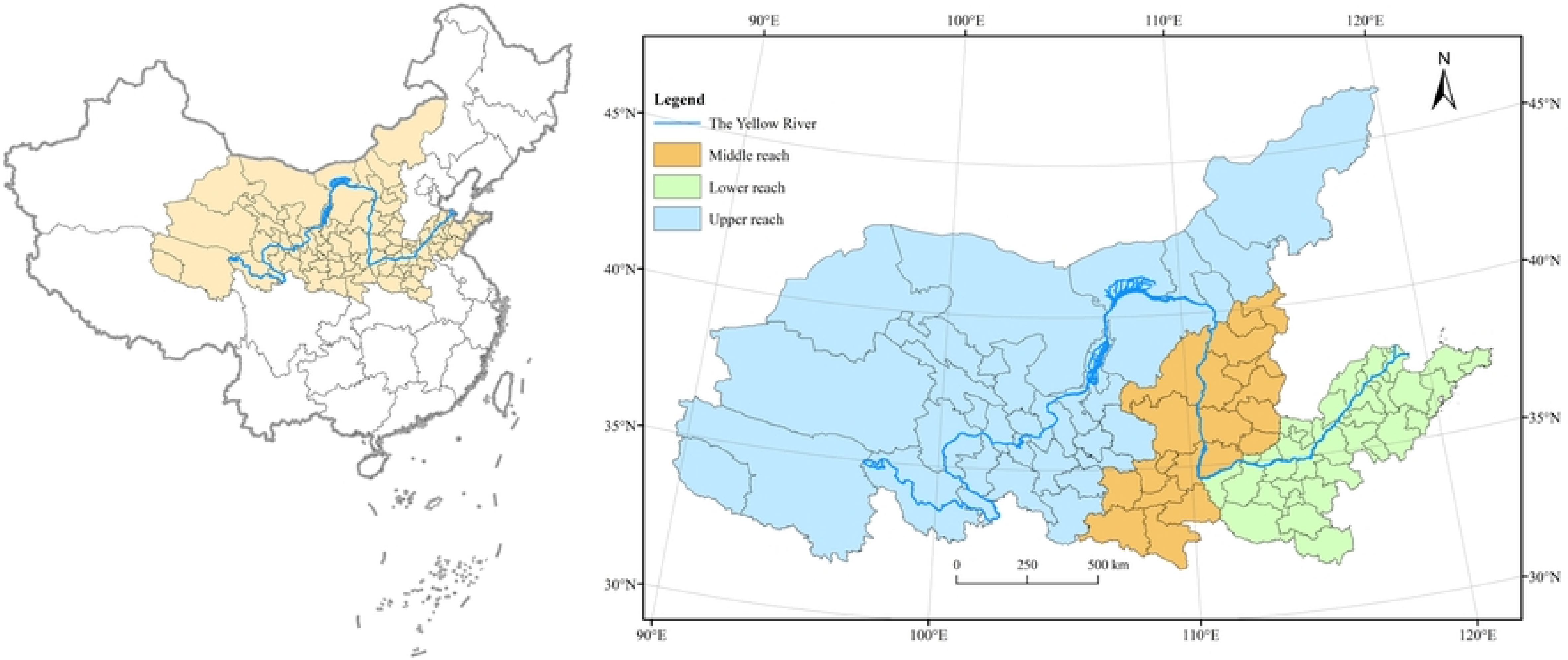
Strategy Environ. 2019; 28, 998–1011. https://doi.org/doi:10.1002/bse.2297

25. Jiang H, Purohit P, Liang Q, et al. The cost-benefit comparisons of China's and India's NDCs based on carbon marginal abatement cost curves. Energy Economics. 2022; 109, 105946. https://doi.org/10.1016/j.eneco.2022.105946
26. Manello A. Productivity growth, environmental regulation and win–win opportunities: The case of chemical industry in Italy and Germany. European Journal of Operational Research. 2017; 262, 733-743. https://doi.org/10.1016/j.ejor.2017.03.058
27. Zhao S, Jiang Y, Wang S. Innovation stages, knowledge spillover, and green economy development: moderating role of absorptive capacity and environmental regulation. Environmental Science and Pollution Research. 2019; 26, 25312-25325. https://doi.org/10.1007/s11356-019-05777-9
28. Ren X, Li J, He F, et al. Impact of climate policy uncertainty on traditional energy and green markets: Evidence from time-varying granger tests. Renewable and Sustainable Energy Reviews. 2023; 173, 113058. https://doi.org/10.1016/j.rser.2022.113058
29. Wang Y, Shen N. Environmental regulation and environmental productivity: The case of China. Renewable and Sustainable Energy Reviews. 2016; 62, 758-766. https://doi.org/10.1016/j.rser.2016.05.048
30. Song C, Liu Q, Song J, et al. Impact path of digital economy on carbon emission efficiency: Mediating effect based on technological innovation. Journal of Environmental Management. 2024; 358, 120940. https://doi.org/10.1016/j.jenvman.2024.120940
31. Liu X, Zuo L, Hu L, et al. Industrial agglomeration, environmental regulation, and carbon emissions reduction under the carbon neutrality goal: Threshold effects based on stages of industrialization in China. Journal of Cleaner Production. 2024; 434, 140064. https://doi.org/10.1016/j.jclepro.2023.140064
32. Song C, Liu Q, Song J, et al. Land Use Efficiency in the Yellow River Basin in the Background of China's Economic Transformation: Spatial-Temporal Characteristics and Influencing Factors. Land. 2022; 11, 2306. https://doi.org/10.3390/land11122306
33. Tong J, Liu W, Xue J. Environmental regulation, factor input structure and industrial transformation. Econ. Res. 2016; 7, 43-57.
34. Zhao J, Shahbaz M, Dong X, et al. How does financial risk affect global CO2 emissions? The role of technological innovation. Technological Forecasting and Social Change. 2021; 168, 120751. https://doi.org/10.1016/j.techfore.2021.120751
35. Dong, Z.Q.; Wang, H. Local-neighborhood effect of green technology of environmental regulation. Chin. Indus. Econ. 2019, 1, 100-118.
36. Cheng Y, Zhang Y, Wang J, et al. The impact of the urban digital economy on China's carbon intensity: Spatial spillover and mediating effect. Resources, Conservation and Recycling. 2023; 189, 106762. https://doi.org/10.1016/j.resconrec.2022.106762
37. Cole M.A, Elliott R.J.R, Okubo T. Trade, environmental regulations and industrial mobility: an industry-level study of Japan. Discussion Paper Series. 2010; 69, 1995-2002.
38. Copeland B.R., Taylor M.S. North-south trade and the environment. Q. J. Econ. 1994; 109, 755-787.
39. Li X, Lai X, Zhang F. Research on green innovation effect of industrial agglomeration from perspective of environmental regulation: Evidence in China. Journal of Cleaner Production. 2021; 288, 125583. https://doi.org/10.1016/j.jclepro.2020.125583
40. Zheng D, Shi M. Multiple environmental policies and pollution haven hypothesis: Evidence from China's polluting industries. Journal of Cleaner Production. 2017; 141, 295-304. https://doi.org/10.1016/j.jclepro.2016.09.091
41. Porter M.E, van der Linde C. Toward a new conception of the environmentcompetitiveness relationship. J. Econ. Perspect. 1995; 9, 97-118.
42. Lai Y.-L, Hsu M.-S, Lin F.-J, et al. The effects of industry cluster knowledge management on innovation performance. Journal of Business Research. 2014; 67, 734-739. https://doi.org/10.1016/j.jbusres.2013.11.036
43. Zhang M, Wang H. Evolution of Industrial Ecology and Analysis of Influencing Factors: The Yellow River Basin in China. Land. 2023; 12, 1277. https://doi.org/10.3390/land12071277

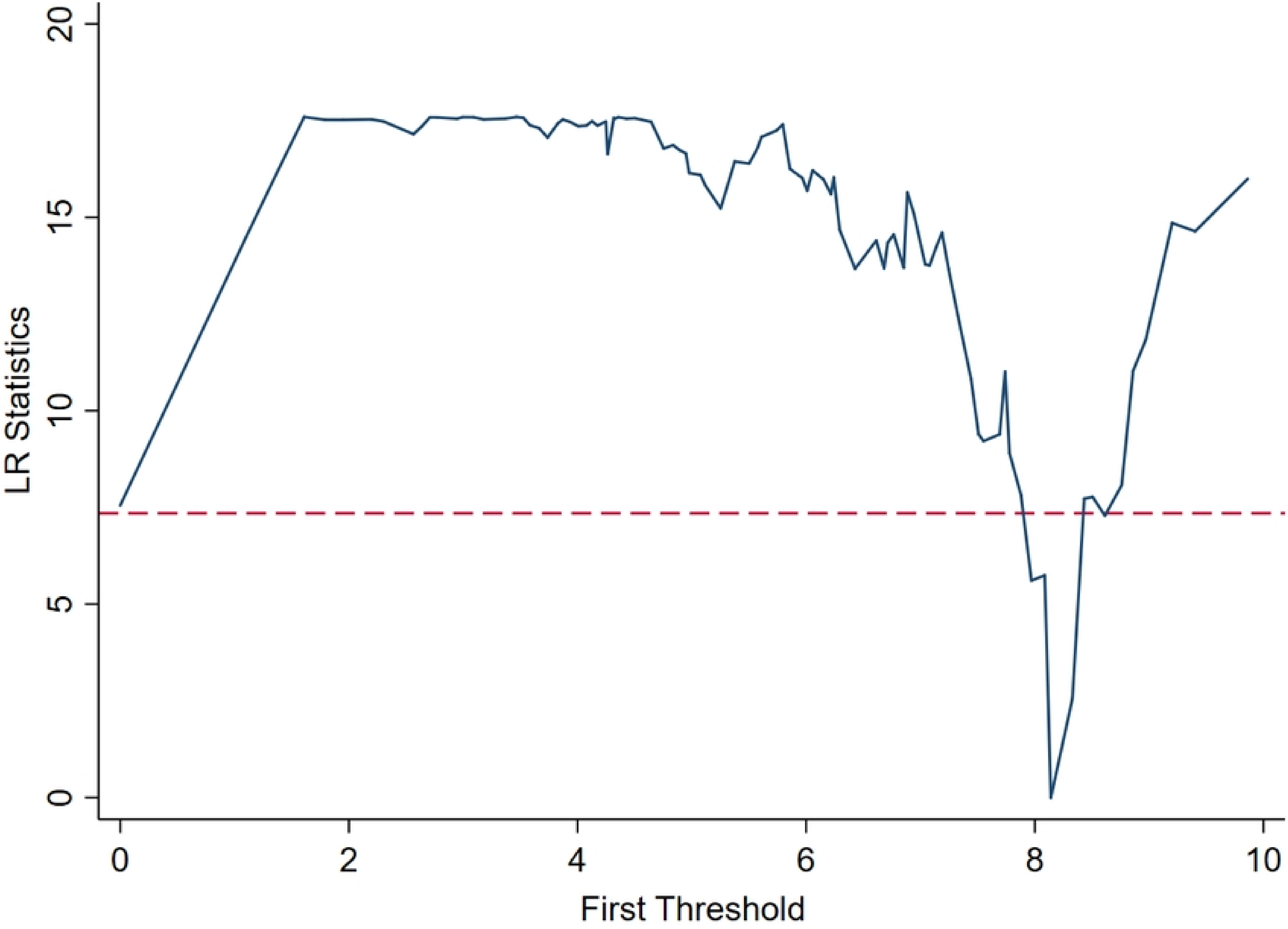
This manuscript is a preprint and has not been peer reviewed. The copyright holder has made the manuscript available under a Creative Commons Attribution 4.0 International (CC BY) license and consented to have it forwarded to EarthArXiv for public posting.


44. Zhang C, Zhao L, Song X, et al. Spatial-temporal coupling characteristics and interaction effects of economic resilience and people's livelihoods and well-being: An analysis of 78 cities in the Yellow River Basin. Sustainable Cities and Society. 2024; 112, 105638. https://doi.org/10.1016/j.scs.2024.105638
45. Charnes A, Cooper W, Rhodes E. Measuring the efficiency of decision making units. European Journal of Operational Research. 1978; 2, 429-444.
46. Tone K. A slacks-based measure of efficiency in data envelopment analysis. European Journal of Operational Research. 2001; 130, 498-509.
47. Tone K. A slacks-based measure of super-efficiency in data envelopment analysis. European Journal of Operational Research. 2002; 143, 31-41.
48. Tobin, J. Estimation of relationships for limited dependent variables. Econometrica. 1958; 26, 24-36.
49. Baron R.M, Kenny D.A. The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. J. Pers. Soc. Psychol. 1986; 51, 1173–1182. https://doi.org/ https://doi.org/10.1177/1350506818764762
50. Hansen B.E. Threshold effects in non-dynamic panels: Estimation, testing, and inference. Journal of econometrics. 1999; 93, 345–368.
51. Cao H, Chen W, Tan X, et al. Identification and driving mechanism of the industrial land use transition in China. Habitat International. 2023; 138, 102848. https://doi.org/10.1016/j.habitatint.2023.102848
52. Hu J, Zhang H. Has green finance optimized the industrial structure in China? Environ Sci Pollut Res Int. 2023; 30, 32926-32941. https://doi.org/10.1007/s11356-022-24514-3
53. Du K, Li J. Towards a green world: How do green technology innovations affect total-factor carbon productivity. Energy Policy. 2019; 131, 240-250. https://doi.org/10.1016/j.enpol.2019.04.033
54. He A, Xue Q, Zhao R, et al. Renewable energy technological innovation, market forces, and carbon emission efficiency. Sci Total Environ. 2021; 796, 148908. https://doi.org/10.1016/j.scitotenv.2021.148908
55. Guo X, Fang C. How does urbanization affect energy carbon emissions under the background of carbon neutrality? J Environ Manage. 2023; 327, 116878. https://doi.org/10.1016/j.jenvman.2022.116878
56. Zhang M, Liu Y. Influence of digital finance and green technology innovation on China's carbon emission efficiency: Empirical analysis based on spatial metrology. Science of The Total Environment. 2022; 838, 156463. https://doi.org/10.1016/j.scitotenv.2022.156463
57. Liu Q, Jiang H, Li J, et al. Antidote or poison? Digital economy and land-use. Land Use Policy. 2024; 139, 107083.
58. Ma Z, Zhou G, Zhang J, et al. Urban shrinkage in the regional multiscale context: Spatial divergence and interaction. Sustainable Cities and Society. 2024; 100, 105020. https://doi.org/10.1016/j.landusepol.2024.107083
59. Zhang X, Yao S, Zheng W, et al. On industrial agglomeration and industrial carbon productivity --- impact mechanism and nonlinear relationship. Energy. 2023; 283, 129047. https://doi.org/10.1016/j.energy.2023.129047
60. Zhang J, Kang L, Li H, et al. The impact of environmental regulations on urban Green innovation efficiency: The case of Xi'an. Sustainable Cities and Society. 2020; 57, 102123. https://doi.org/10.1016/j.scs.2020.102123

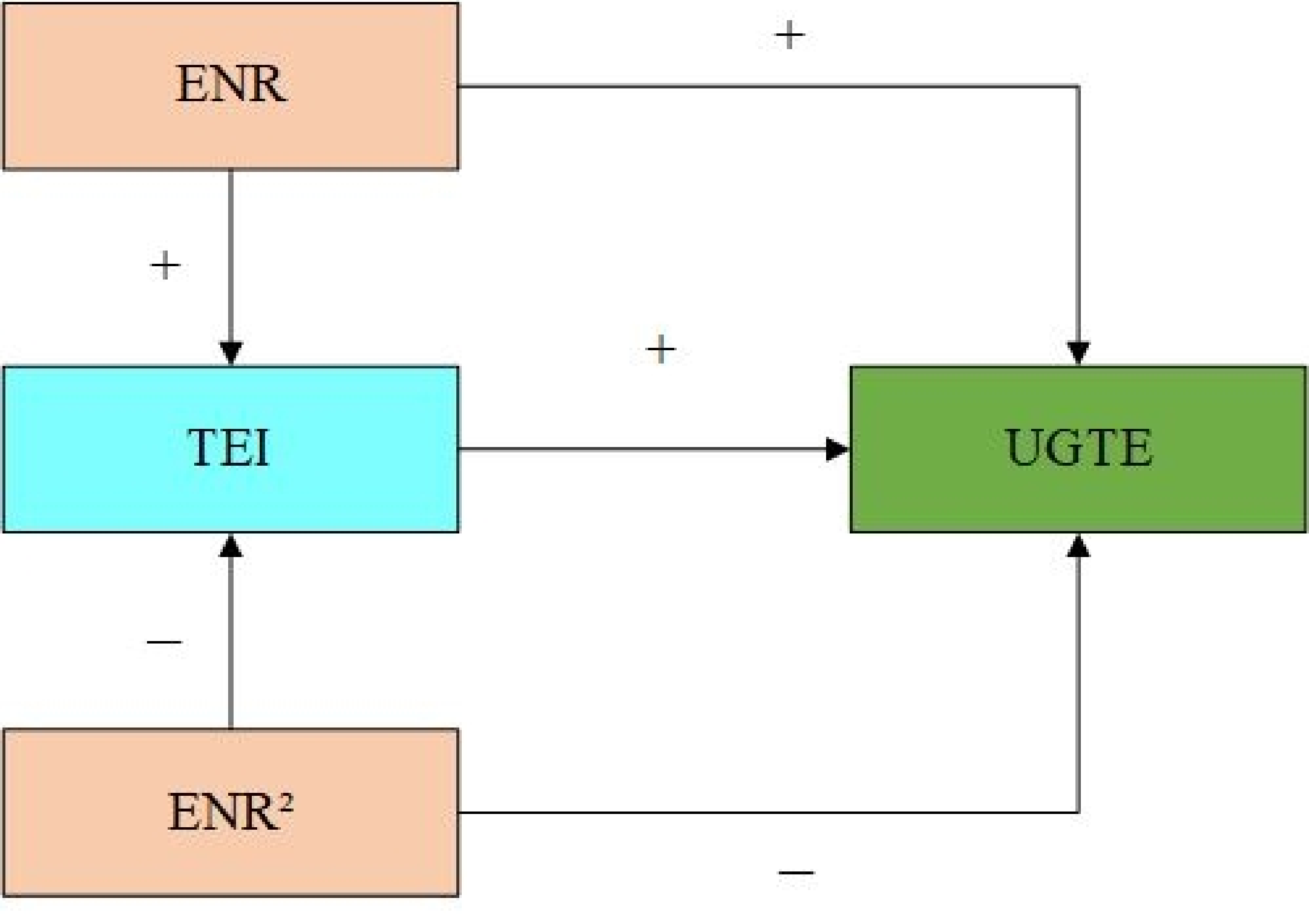

Mediating effect
Technological innovation
Productivity improvement
Reduce pollution emission
Increase enterprise cost
Direct effect
Increase unemployment
ENR
UGTE
Economic growth
Reduce pollution emission
Scale effect
Industrial agglomeration
Technology spillover effect
Mediating effect



Legend
The Yellow River
Middle reach
Lower reach
Upper reach
N
0
250
500 km
90°E
100°E
110°E
120°E
45°N
40°N
35°N
30°N



LR Statistics
20
15
10
5
0
0
2
4
6
8
10
First Threshold


ENR
+
+
+
TEI
UGTE
−
$ENR^2$
−