

Original Research

The Impact of Environmental Regulation on Logistics Efficiency along the Yangtze River Economic Belt

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Abstract

With the Chinese government promoting the “Double Carbon” policy and high-economic development, environmental regulation and economic efficiency research has become a hot topic. However, existing research focuses on industrial economic efficiency, ignoring logistics industry, which has high emissions and energy consumption. Based on provincial panel data from China’s Yangtze River Economic Belt from 2009 to 2020, this paper uses a super-SBM, which includes undesirable outputs and is combined with the Global Malmquist-Luenberger (GML) index, to measure and analyze the regional logistics efficiency. Panel regression and threshold regression models are used to test the impact of formal and informal environmental regulations on logistics efficiency, rather than the common single perspective. The results indicate that: (1) Environmental regulation has a significant impact on the overall logistics efficiency of the Yangtze River Economic Belt during the study period, and there is a problem of regional development incongruity. The maximum difference in logistics efficiency between provinces is 0.5637. (2) The impact mechanism of formal and informal environmental regulations differs, and each percentage of informal environmental regulation has a promotion effect on logistics efficiency that is 0.0827% higher than that of formal environmental regulation. (3) Formal environmental regulation has a single threshold effect on logistics efficiency, whereas informal environmental regulation has a double threshold effect, demonstrating that overregulation can have the opposite effect. Based on different regulatory tools, this paper makes pertinent recommendations to promote the coordinated development of the logistics industry’s economic and environmental benefits in the Yangtze River Economic Belt.

Keywords: Yangtze River Economic Belt, environmental regulation, logistics efficiency, Super-SBM, GML index

Introduction

Yangtze River Economic Belt is an important engine of China's economic growth. Relying on convenient transportation and favorable location, the logistics industry in Yangtze River Economic Belt has been developing rapidly. However, the carbon emission of logistics industry in the Yangtze River Economic Belt reached 344.8141 million tons in 2020, accounting for about 44.67% of the national carbon emission [1, 2]. As a model pilot belt for ecological civilization construction in China, the problem of continuous growth of carbon emissions from the logistics industry has received great attention from relevant departments. The central and local governments have promulgated a large number of regulations and policies in pollution control, energy conservation and circular economy, etc. These environmental regulations can improve the impact of logistics on the environment to a certain extent, but what is its impact on logistics efficiency is also a question worth exploring.

It has been pointed out that environmental regulation is one of the important measures to control environmental pollution by intervening in the behavior of enterprises [3, 4], which can have a positive impact on green technology innovation, carbon emissions, and total factor productivity through relevant policies [5-7]. However, most of the existing studies only examine the impacts of environmental regulations in general, and such a general examination may lead to a certain degree of reduction in the practicability and validity of the findings [8, 9]. In fact, the impacts of different types and degrees of environmental regulation intensity are different. To address this, this paper subdivides environmental regulations into formal and informal environmental regulations as a way to test the implementation effects of different regulatory tools, so as to strengthen the practicability of the findings, provide policy references and evidence for government managers, and promote the green and circular development of the logistics industry in the Yangtze River Economic Belt.

In addition, although some important results have been obtained, the studies on environmental regulation and logistics industry efficiency have not yet reached consistent conclusions [10-12], and there is little literature to explore the mechanism of environmental regulation on logistics industry efficiency. Therefore, this paper presents a detailed analysis of the impact mechanism of environmental regulation on the efficiency of the logistics industry to provide an adequate theoretical basis for the subsequent empirical analysis.

Literature Review

Environmental Regulation

The empirical study of environmental regulation intensity is based on environmental regulation intensity

measurement. However, the measurement remains contentious due to a lack of completely independent regulatory tools and a standardized government intervention model.

To measure the intensity of environmental regulation in different countries, Walter and Ugelow sent questionnaires to Member States of the United Nations via the United Nations Conference on Trade and Development [13]. Tobey refined the method to examine the relationship between environmental regulation and trade patterns [14]. Aside from qualitative methods, some studies use quantitative indicators to measure things like environmental investment and supervision. Du et al. measured the impact of environmental regulation using the ratio of industrial pollution control investment to gross value of industrial enterprises [15]. Instead of using the proportion of industrial pollution control investment in the second industry, Liu and He used the proportion of industrial pollution control investment [16]. Wang et al. used the share of pollution treatment investment [17]. Considering that environmental regulation interact with a variety of factors, the comprehensive index method is used to avoid measurement bias [18, 19].

In terms of economic benefits, China is in the critical period of economic transition and upgrade. The environment has evolved into an effective productivity factor for ensuring high-quality economic development. However, environmental governance cannot be achieved solely through the strength of market mechanisms; effective utilization of environmental regulation is also required. The "dilemma" between environmental protection and economic growth has sparked considerable debate [20, 21]. According to some studies, the implementation of environmental regulation raises enterprise operating costs, which crowd out funds for production and investment (i.e. internalization of pollution costs and compression of profit space), thereby limiting enterprises production efficiency and even local economic growth [22, 23]. In comparison, the "Porter hypothesis" demonstrated that environmental regulation is not incompatible with economic development. Reasonable and forceful environmental regulation will actually spur enterprises to carry out innovation activities while also enhancing their own competitiveness, neutralizing environmental burden costs, obtaining innovational spillover, and forcing the growth of production efficiency and regional economy [24, 25]. Furthermore, some studies have found that regulatory tools, regulatory intensity, regional economy, industrial pollution, and other factors all have an impact on the impact of environmental regulation [26-28].

Logistics Efficiency

Data envelopment analysis (DEA), which was published in 1978, is the most widely used method for evaluating logistics efficiency [29]. The advantage of DEA is that it is not constrained by function form and can effectively measure the efficiency of actual

manufacturing process. Schinnar took the lead in proposing the idea of applying DEA model to the efficiency research of logistics industry [30]. Weber applied DEA model to supply chain management, evaluating the service performance of six suppliers of a pharmaceutical enterprise [31]. Stochastic frontier analysis (SFA) is another commonly used method for measuring logistics efficiency. Considering regional heterogeneity, some studies established the SFA model based on Cobb-Douglas function to measure the provincial level logistics efficiency in China [32]. Some studies have also applied optimal combinations of SFA and DEA models [33, 34].

Because of regional economic development differences, the input of logistics infrastructure, human capital, industrial structure and other locational factors is distinguishing. Hence, the factors influencing logistics efficiency vary by region. Wu studies the top five GDP cities in China and found that the core influencing factors of logistics efficiency differed between provinces and cities [35]. Besides, technological development, low carbon development, environmental changes and other factors are thought to be related to logistics efficiency [36-39]. There is also a large body of literature that has studied DEA and has explored various applications of DEA [40-42].

Impact of Environmental Regulation on Logistics Efficiency

Research community has begun to pay attention to the negative impact of logistics production and operation on ecological environment for the past few years. The results differ due to the various methods and indicators used [43-45].

Some studies hold that the correlation between environmental regulation and logistics efficiency is positive, Zhang used the proportion of environmental pollution control investment in GDP to measure environmental regulation, and the Tobit regression revealed that environmental regulation hampered logistics efficiency in China because the cost of environmental protection exceeded the profit from

innovation [46]. Some studies also pointed out, increasing environmental awareness contributes to the logistics industry's long-term development [47-49].

In addition to above, some studies used different models (e.g. hierarchical regression) to test the hypothesis that environmental regulation have nonlinear effects on logistics efficiency. Tang et al. took the gross of environmental investment as the environmental regulation variable, found that environmental regulation has a double threshold effect on logistics efficiency, and the promotion effect showed a gradient declining trend [50]. Using the DEA model and hierarchical regression, Zheng et al. found environmental regulation has a seesaw effect on logistics economic performance and environmental performance [51].

Methodology

Theoretical Analysis and Hypothesis

Environmental regulation can be classified as formal or informal depending on the subject of implementation. Formal environmental regulation, as depicted in Fig. 1, refers to a series of policies and measures adopted by government departments to address ecological and environmental problems, such as effluent standards, emission taxation, and other command or economic methods to order or anti-driving enterprises from carrying out environmental pollution treatment. According to existing studies, the effects of formal environmental regulation on logistics efficiency can be represented as “crowding out effect” and “innovation compensation effect” [52, 53].

Informal environmental regulation refers to the constrained force generated by NGOs, the public, and other groups on environmental issues, i.e., environmental appeals and actions by the public, media, or social groups that reduce pollution and protect the environment. According to existing research, informal environmental regulation can affect the logistics efficiency via “demand anti-driving effect” and “external constraint effect” [54, 55], as illustrated in Fig. 2.

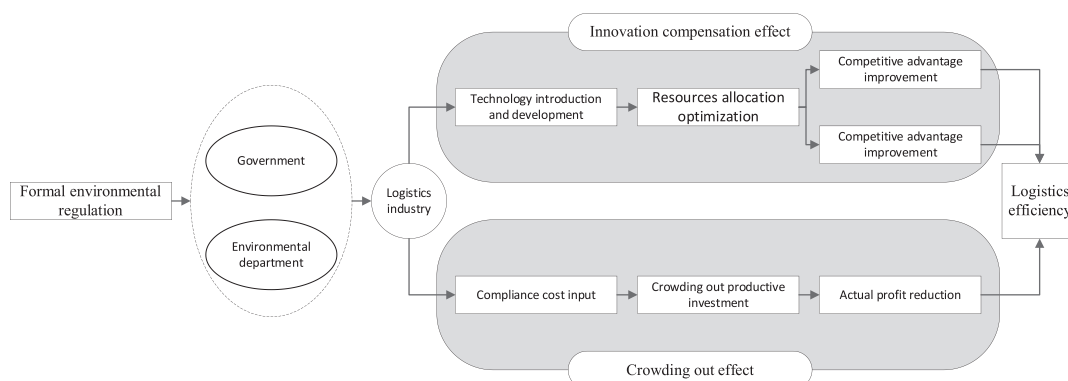


Fig. 1. The impact path of formal environmental regulation.

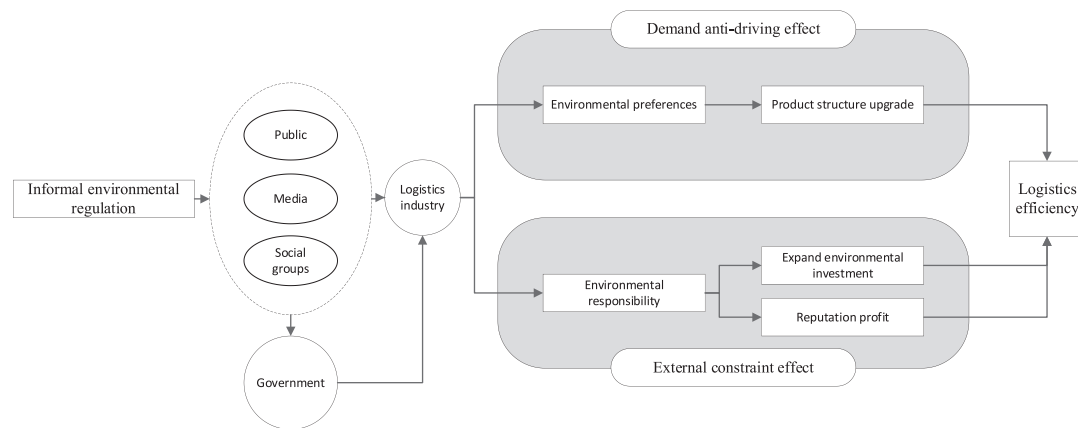


Fig. 2. The impact path of informal environmental regulation.

When combined with the impact mechanism of environmental regulation, enterprises compelled by environmental constraints may stimulate reform motivation, optimize resources allocation, enhance profitability and production efficiency by upgrading and adjusting product structure, business decisions, and production technology [56, 57]. In the long run, environmental regulation will play the role of survival of the fittest, eliminating the logistics enterprises that are not environmentally friendly or economical viable, reallocating resources to efficient enterprises, and ultimately driving overall industry efficiency to achieve high-quality development [58-61]. In addition to the above literature, this study summarizes other relevant literature accordingly [62, 63]. Based on the foregoing, it is proposed that:

H1: Formal environmental regulation has anti-driving effect on logistics efficiency.

H2a: Informal environmental regulation has anti-driving effect on logistics efficiency.

It should be noted that as environmental management system transformation accelerates, the authority of environmental regulation gradually decentralises, environmental information becomes more transparent, the initiative of public participation in environmental governance grows stronger, and further evolves into a powerful informal environmental regulation. Furthermore, in the internet age, the level of environmental information disclosure has increased, the promptness of public participation has been guaranteed, the contradiction of information asymmetry in environmental governance has been improved, and the role of informal environmental regulation on industrial efficiency has been enhanced [64]. Based on the above discussion:

H2b: Compared with formal environmental regulation, informal environmental regulation has more obvious anti-driving effect on logistics efficiency.

The impact path of on logistics efficiency can be divided into “crowding out effect” and “innovation compensation effect” from the standpoint of formal environmental regulation. The intensity of the

“innovation compensation effect,” according to the “Porter hypothesis”, is the key to achieving win-win economic and environmental benefits in logistics industry. In general, the R&D cycle for green technology is relatively long, expensive, and low-income, with uncertainty and hysteresis.

If formal environmental regulation is overly stringent, enterprise innovation enthusiasm may be dampened, and a relatively large amount of funds will be invested in the undesirable output governance, squeezing out the technological innovation funds. If the environmental regulation is weak, although it provides a relatively relaxed environment for innovation, it also weakens the regulatory power of environmental issues, and the undesirable output will increase in the short term [65, 66]. This paper hypothesizes that there is an optimal interval of formal environmental regulation during which the undesirable output can be reduced, the profitability and controllability of innovation can be ensured, and transformation and upgrading can be promoted. This suggests that the relationship between formal environmental regulation and logistics efficiency may be nonlinear. Based on the above, it is proposed that:

H3: The impact of formal environmental regulation on logistics efficiency is nonlinear, and the impact degree of different regulation intensity is different.

It can effectively urge logistics enterprises as a supplementary role for environmental regulation from the standpoint of informal environmental regulation. The “demand antidriving effect” can encourage enterprises to adopt a green environmental protection concept, provide more green products and services, reduce undesirable output [67, 68]. However, there may be a reversal of the “external constraint effect”, in which, due to the emotional nature of spontaneous environmental protection behavior, when the public becomes irrational, it may have a negative impact on the profitability of logistics enterprises, affecting the normal operation of industry [69]. Based on the above discussion:

H4: The promote effect of informal environmental regulation on logistics efficiency is nonlinear.

Econometric Models

Super-efficient SBM Model Considering Undesirable Outputs

Tone developed a slacks-based measure (SBM) that takes into account undesirable output to address the shortcomings of the traditional DEA model [70]. Then Tone broadened the definition and proposed a slacks-based measure of super-efficiency (super-SBM) to solve the multiple DMU sequencing problem [71].

Tone's research is used in this paper to describe the level of regional logistics efficiency using the super-SBM model with undesirable output. Suppose there are n DMUs, and each DMU contains m input factors, r_1 desirable output factors and r_2 undesirable output factors. The vector expressions are $x \in R^m$, $y^d \in R^{r_1}$, $y^u \in R^{r_2}$ respectively. X , Y^d and Y^u denote the matrices of input, desirable output and undesirable output respectively, ρ denotes logistics efficiency value. The basic form is shown in Eq. (1).

$$\begin{aligned} \min \rho &= \frac{1 + \frac{1}{m} \sum_{i=1}^m \frac{w_i^-}{x_{ik}}}{1 - \frac{1}{r_1 + r_2} (\sum_{s=1}^{r_1} \frac{w_s^d}{y_{sk}^d} + \sum_{q=1}^{r_2} \frac{w_q^u}{y_{qk}^u})} \\ \text{s.t. } x_{ik} &\geq \sum_{j=1, j \neq k}^n x_{ij} \lambda_j - w_i^- \\ y_{sk}^d &\leq \sum_{j=1, j \neq k}^n y_{sj} \lambda_j + w_s^d \\ y_{qk}^u &\geq \sum_{j=1, j \neq k}^n y_{qj} \lambda_j - w_q^u \\ \sum_{j=1, j \neq k}^n \lambda_j &= 1; \lambda_j, w_s^d, w_q^u \geq 0 \\ i &= 1, 2, \dots, m; \quad s = 1, 2, \dots, r_1; \quad q = 1, 2, \dots, r_2; \\ j &= 1, 2, \dots, n \quad (j \neq k) \end{aligned} \tag{1}$$

Super-efficiency SBM Model

Oh proposed a Global Malmquist-Luenberger (GML) index. All DMU data from the sample period are used to construct a common production frontier that is transferable and can be used to solve the problem of no solution caused by production frontier movement [72].

According to Oh's research, the GML index model is shown in Eq. (2).

$$GML_t^{t+1} = \frac{1 + \bar{D}_0^G(x^t, y^t, b^t; -x^t, y^t, -b^t)}{1 + \bar{D}_0^G(x^{t+1}, y^{t+1}, b^{t+1}; -x^{t+1}, y^{t+1}, -b^{t+1})} \tag{2}$$

If $GML_t^{t+1} > 1$ represents the total factor productivity of logistics industry has increased from period t to $t + 1$; if $GML_t^{t+1} < 1$, the total factor productivity of logistics industry has decreased. Besides, GML_t^{t+1} index can be divided into two parts, i.e., global technical efficiency change index (GTC_t^{t+1}) and global technological progress change index (GEC_t^{t+1}). It is shown in Eq. (3), Eq. (4) and Eq. (5).

$$GML_t^{t+1} = GEC_t^{t+1} \times GTC_t^{t+1} \tag{3}$$

$$GEC_t^{t+1} = \frac{1 + \bar{D}_0^G(x^t, y^t, b^t; -x^t, y^t, -b^t)}{1 + \bar{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; -x^{t+1}, y^{t+1}, -b^{t+1})} \tag{4}$$

$$GTC_t^{t+1} = \frac{\frac{1 + \bar{D}_0^G(x^t, y^t, b^t; -x^t, y^t, -b^t)}{1 + \bar{D}_0^G(x^t, y^t, b^t; -x^t, y^t, -b^t)}}{\frac{1 + \bar{D}_0^G(x^{t+1}, y^{t+1}, b^{t+1}; -x^{t+1}, y^{t+1}, -b^{t+1})}{1 + \bar{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; -x^{t+1}, y^{t+1}, -b^{t+1})}} \tag{5}$$

Where $GEC_t^{t+1} > 1$ indicates that technical efficiency improvement contributes to logistics efficiency; $GTC_t^{t+1} > 1$ indicates that technological progress contributes to logistics efficiency growth.

In this paper, GML index model will be used to dynamically measure the logistics efficiency along the Yangtze River Economic Belt, so as to analyze the dynamic change trend and driving factors.

Panel Regression Model

To test the impact of environmental regulation on logistics efficiency, formal and informal environmental regulation are taken as the core explanatory variables, and other factors are controlled by explanatory variables, and panel regression model is built for empirical analysis. To solve the possible heteroscedasticity and multicollinearity interference, take the logarithm of the absolute quantity. The model is represented as Eq. (6) and Eq. (7).

$$\begin{aligned} LE_{it} &= \alpha_0 + \alpha_1 FER_{it} + \alpha_2 \ln pgdp_{it} + \alpha_3 gov_{it} \\ &+ \alpha_4 info_{it} + \alpha_5 tran_{it} + \alpha_6 agg_{it} + \varepsilon_{it} \end{aligned} \tag{6}$$

$$\begin{aligned} LE_{it} &= \beta_0 + \beta_1 INER_{it} + \beta_2 \ln pgdp_{it} + \beta_3 gov_{it} \\ &+ \beta_4 info_{it} + \beta_5 tran_{it} + \beta_6 agg_{it} + \varepsilon_{it} \end{aligned} \tag{7}$$

Where i denotes the provinces ($i = 1, 2, \dots, 11$), t denotes the year, LE denotes logistics efficiency. This paper divided environmental regulation intensity into formal environmental regulation (FER) and informal environmental regulation ($INER$). Besides, $\ln pgdp$ denotes real GDP per capita, gov denotes government intervention degree, $info$ denotes informationalized level, $tran$ denotes traffic infrastructure construction, agg denotes logistics industrial agglomeration level, ε is the residual term, α_0, \dots, β_6 are regression parameters of each index.

Among them, *lngdp* is expressed in the real GDP per capita. By referring to Cao et al., *gov* is expressed in the proportion of local fiscal environmental protection expenditure to total fiscal expenditure and *info* is expressed by internet penetration [73]. The proportion of total mileage of railways, highways, and waterways in administrative divisions represents the *tran* and the level of traffic infrastructure construction in each region. Besides, this paper evaluates logistics agglomeration degree with location entropy index, the formula is shown in Eq. (8).

$$agg_{ij} = \frac{E_{ij}/E_i}{L_j/L} \tag{8}$$

Where agg_{ij} is the logistics agglomeration degree in region i , the higher the value, the higher the degree. E_i is the total number of employment in region L , L_j and i denote the total number of employment in national logistics industry and in the whole nation respectively.

Threshold Regression Model

Environmental regulation has a multifaceted impact on logistics efficiency, and the degree of impact varies depending on the intensity of environmental regulation. In this regard, the panel threshold regression model proposed by Hansen is used to test whether the relationship between environmental regulation and logistics industry efficiency is nonlinear [74]. The formula is shown in Eq. (9) and Eq. (10).

$$LE_{it} = \delta_0 + \delta_1 FER_{it} \cdot I(FER_{it} \leq \gamma) + \delta_2 FER_{it} \cdot I(FER_{it} > \gamma) + \delta_3 \ln p gdp_{it} + \delta_4 gov_{it} + \delta_5 info_{it} + \delta_6 tran_{it} + \delta_7 agg_{it} + \varepsilon_{it} \tag{9}$$

$$LE_{it} = \varphi_0 + \varphi_1 INER_{it} \cdot I(INER_{it} \leq \theta) + \varphi_2 INER_{it} \cdot I(INER_{it} > \theta) + \varphi_3 \ln p gdp_{it} + \varphi_4 gov_{it} + \varphi_5 info_{it} + \varphi_6 tran_{it} + \varphi_7 agg_{it} + \varepsilon_{it} \tag{10}$$

Where $I(\cdot)$ represents characteristic function, when the expression in parentheses is false, the value is 0; otherwise, the value is 1. FER and $INER$ as threshold variables. γ and θ as specific threshold values.

Indicators and Data Sources

This paper’s research period is set from 2009 to 2020. On the one hand, since the concept of low-carbon living was put forward at the United Nations Climate Change conference in 2009, governments from all countries have been actively committed to strengthening environmental regulation intensity. Therefore, the year 2009 is chosen as the starting point. On the other hand, some data is released late, so 2020 was chosen as the end point based on data availability and consistency.

Measurement of Logistics Efficiency

This paper takes 11 provinces and cities along the Yangtze River Economic Belt as the 11 DMUs, i.e., Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Guizhou and Yunnan. The data come from China Statistical Yearbook, China Energy Statistical Yearbook and statistical yearbooks of provinces and cities from 2010 to 2021. Fig. 3 depicts the geographical locations of provinces and cities along the Yangtze River Economic Belt.

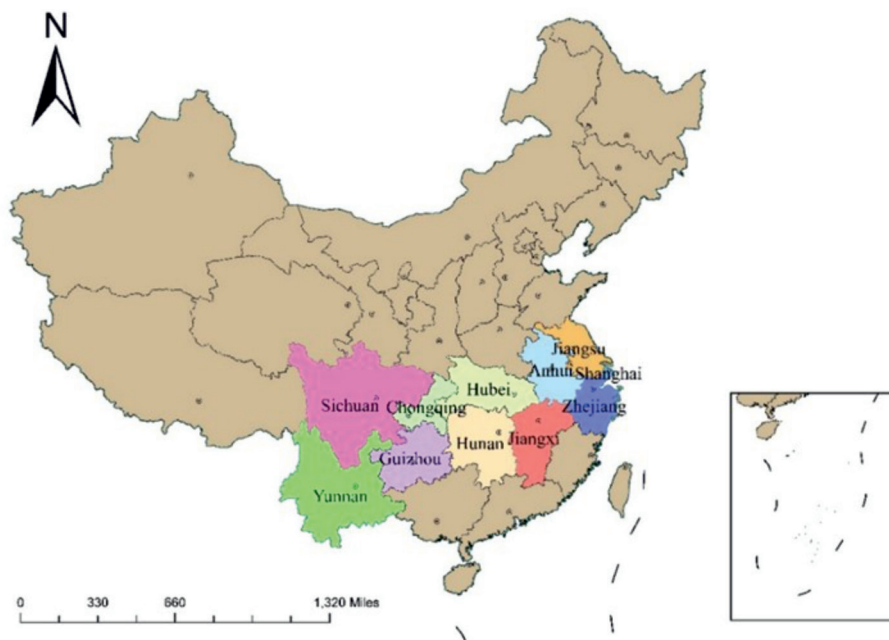


Fig. 3. Geographical locations of the 11 study regions.

In terms of input indicators, in the China Statistical Yearbook, there are no complete statistics on logistics industry. According to Zheng et al., this paper use the investment in fixed assets and employees of transportation, warehousing, and postal industries to measure logistics efficiency [51]. Referring to Cao et al., the length of railway operation, highway, and inland river navigation are selected to measure the infrastructure investment [73]. According to Liu and Guan, eight types of energy with the highest consumption in logistics industry are selected for measurement based on the energy reference calorific value and the standard coal coefficient in the “China Energy Statistical Yearbook” uniformly converted into standard coal for measurement [75].

Output indicators can be divided into desirable output and undesirable output. The desirable output is expressed in terms of the output value from transportation, warehousing, and postal industries. As no official data on the logistics industry’s three waste emissions has been released, previous studies have used the carbon dioxide emission generated by logistics activities is taken as a proxy variable [76, 77].

Therefore, the index system considers 4 inputs and 2 outputs, including 1 desirable output and 1 undesirable output, as shown in Table 1.

Impact of Environmental Regulation on Logistics Industry Efficiency

Formal Environmental Regulation Indicator

The comprehensive index method is used in this paper to objectively evaluate formal environmental regulations in order to ensure data comparability and indicator comprehensiveness. According to Dong and Wang, three indexes of wastewater, SO₂, and somke dust were chosen for measurement. The procedure is expressed using the formulas below [78].

$$DE_{ij}^* = \frac{DE_{ij} - \min(DE_j)}{\max(DE_j) - \min(DE_j)} \tag{11}$$

$$W_j = \frac{DE_{ij}}{DE_{ij}^*} \tag{12}$$

$$DFER_i = \frac{1}{3} \sum_{j=1}^3 W_j DE_{ij}^* \tag{13}$$

Here, DE_{ij}^* represents standardized value of single indicator, DE_{ij} represents emission per unit output value of j pollutant in i province, $\min(DE_j)$ and $\max(DE_j)$ represent minimum and maximum emissions per unit output value of j pollutant in each province respectively. W_j represents regulatory coefficient, $\overline{DE_j}$ represents average emission level of j pollutant per unit output value within the sample interval. To make the index value consistent with the action direction, this paper refers to Weng et al., the above indicators are processed inversely and logarithmically to obtain the formal environmental regulation intensity (FER_i) of i province [79].

Informal Environmental Regulation Indicator

Based on previous research, this paper selects three indicators, namely income level, education level, and age structure, and employs the entropy method to objectively evaluate the informal environmental regulation intensity [55, 80]. The specific methods are as follows.

$$X_{ij}^* = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)} \tag{14}$$

$$E_j = -\frac{1}{\ln m} \sum_{i=1}^m p_{ij} \ln p_{ij} \tag{15}$$

$$p_{ij} = \frac{X_{ij}^*}{\sum_{i=1}^m X_{ij}^*} \tag{16}$$

$$Z_j = \frac{1 - E_j}{3 - \sum_{j=1}^3 E_j} \tag{17}$$

$$INER_i = \sum_{j=1}^3 Z_j X_{ij}^* \tag{18}$$

Here, X_{ij} and X_{ij}^* represents original and standardized value of j in i province respectively, E_j is entropy value of j , p_{ij} is the proportion of j . $INER_i$ is informal environmental regulation intensity in i province.

Table 1. The input and output indicators.

	Indicator	Definition (Unit)
Input	Economic aspect	The capital stock of transportation, warehousing and postal industries (Hundred million yuan)
	Labor aspect	The employees of transportation, warehousing and postal industries (Ten thousands persons)
	Infrastructure aspect	The length of railway operation, highway and inland river navigation (Ten thousands kilometers)
	Energy aspect	Energy consumption of transportation, warehousing and postal industries (Ten thousands tons)
Output	Desirable ouput	The output value of transportation, warehousing and postal industries (Hundred million yuan)
	Undesirable output	The carbon dioxide emission generated in logistics activities (Ten thousands tons)

Results and Discussion

Static Logistics Efficiency along Yangtze River Economic Belt

The logistics efficiency of 11 provinces and cities along the Yangtze River Economic Belt is measured using the Super-efficiency SBM model, and the investigation period is set from 2009 to 2020. The time series evolution result is measured from the overall, watershed and provincial levels.

According to the time series evolution of mean static efficiency in Fig. 4 and Fig. 5, from 2009 to 2020, the overall efficiency level of the logistics industry along the Yangtze River Economic Belt is not high, with an average efficiency during the inspection period of only about 0.59 indicating a significant room for improvement. Time series analysis shows that the efficiency of China's logistics industry is vulnerable to the impact of environmental regulation, but the duration of policy dividend is short and there is some lag.

Fig. 6 depicts logistics efficiency in each watershed of the Yangtze River Economic Belt from 2009 to 2020. Each watershed's efficiency trend is similar to that of the entire system, however, the overall efficiency of the upstream is obviously higher than that of the middle and downstream.

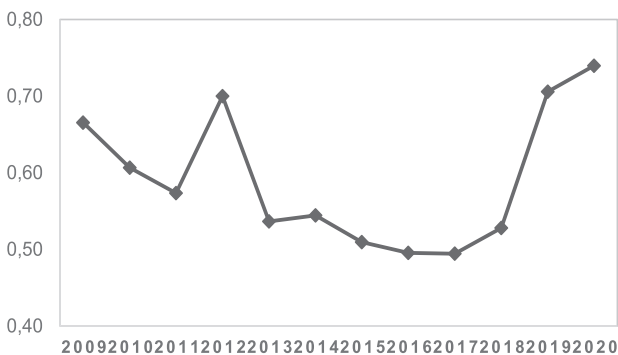
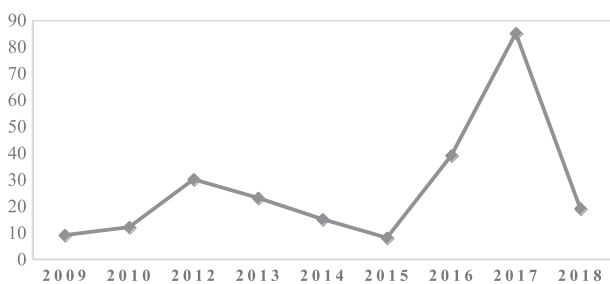


Fig. 4. The average logistics efficiency along the Yangtze River Economic Belt.



Note: In 2012 and 2020, China's environmental yearbook did not release the number of regulations, 2021 China Environmental Yearbook has not been released yet.

Fig. 5. Number of local environmental protection regulation issued along the Yangtze River Economic Belt.

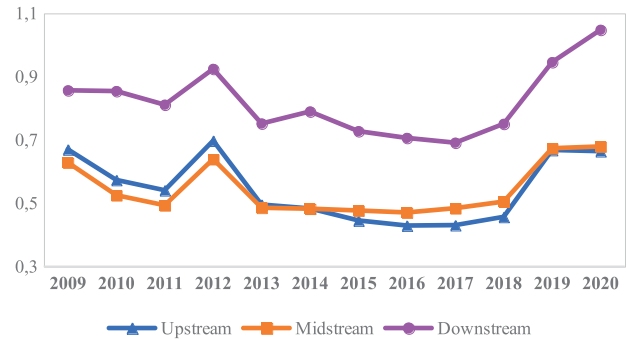


Fig. 6. The Change of Logistics efficiency along the Yangtze River Economic Belt from the perspective of watershed.

Fig. 7 depicts the logistics efficiency value in 11 provinces and cities along the Yangtze River Economic Belt from 2009 to 2020. From the provincial standpoint, the average logistics efficiency between provinces and cities differed significantly. The average annual growth rate of logistics efficiency in most provinces is positive, but negative in Jiangxi and Chongqing. Among them, the logistics efficiency in Sichuan has improved significantly in the last two years, with the highest average annual growth rate(AAGR). In addition, Chongqing has the highest deceleration.

This paper takes 3-4 years as a sub-period, chooses 2009, 2013, 2016, and 2020 as representative years, and draws a spatial distribution map as shown in Fig. 8.

In terms of overall layout, the logistics efficiency of the Yangtze River Economic Belt has a zonal pattern, with high in the east and low in the west. This phenomenon becomes more visible as time passes. The downstream area has always been high, and the gap between midstream and downstream has gradually widened. The logistics efficiency values in Sichuan and Yunnan have markedly improved in the last two years.

Dynamic Logistics Efficiency along Yangtze River Economic Belt

Static analysis using SBM model can understand the spatiotemporal distribution difference of logistics efficiency along the Yangtze River Economic Belt from many aspects, however, it is difficult to explain in detail why logistics efficiency changed during the research period. Therefore, the GML index is introduced to dynamically analyse logistics efficiency, and the GML index is divided into the global technical efficiency change index (GEC) and the global technical progress change index (GTC), with the following calculation results.

As shown in Table 2, the average GML_t^{t+1} of the logistics industry along the Yangtze River Economic Belt has reached 1.029, both GEC and GTC show an upward trend.

As shown in Fig. 9, the following conclusions are drawn from an examination of the various reaches of the Yangtze River Economic Belt: overall, the GML_t^{t+1}

	Anhui	Guizhou	Hubei	Hunan	Jiangsu	Jiangxi	Shanghai	Sichuan	Yunnan	Zhejiang	Chongqing
2009	1.0295	1.0000	0.3974	0.4862	0.6878	1.0000	1.0000	0.3198	0.3575	0.7058	1.0000
2010	1.0000	0.7623	0.4084	0.4508	0.7221	0.7145	1.0000	0.3085	0.3755	0.6917	0.8454
2011	0.8763	0.7028	0.3865	0.4143	0.7643	0.6777	0.9550	0.3121	0.3546	0.6463	0.7911
2012	1.0000	1.0000	0.4180	0.4982	1.0206	1.0000	1.0000	0.3202	0.4669	0.6737	1.0000
2013	0.7531	0.6862	0.4174	0.4592	0.7061	0.5778	0.8947	0.3058	0.3894	0.6499	0.5980
2014	0.8077	0.6824	0.4196	0.4567	0.6923	0.5698	1.0000	0.2885	0.372	0.6558	0.5877
2015	0.7971	0.5825	0.4279	0.4483	0.6115	0.5528	0.8377	0.3135	0.384	0.6609	0.4990
2016	0.7880	0.5365	0.3973	0.4531	0.6144	0.5597	0.7388	0.3025	0.3867	0.6806	0.4892
2017	0.7433	0.5609	0.4165	0.4746	0.6188	0.5598	0.7160	0.2987	0.3943	0.6836	0.4660
2018	0.8269	0.5791	0.4226	0.5172	0.6394	0.5730	0.8212	0.3296	0.4047	0.7125	0.5111
2019	0.8842	1.0000	0.5925	0.7251	0.8381	0.7011	1.0564	0.6294	0.5136	1.0009	0.5270
2020	1.0529	1.0000	0.6168	0.7231	1.0837	0.6952	1.0517	0.6035	0.5180	1.0000	0.5324
Avg.	0.8799	0.7577	0.4434	0.5089	0.7499	0.6818	0.9226	0.3610	0.4098	0.7301	0.6539
Rank	2	3	9	8	4	6	1	11	10	5	7
AAGR	0.96%	3.34%	4.67%	4.49%	5.89%	-0.69%	1.20%	8.29%	4.22%	3.81%	-4.13%

Fig. 7. Logistics efficiency along the Yangtze River Economic Belt from the provincial perspective.

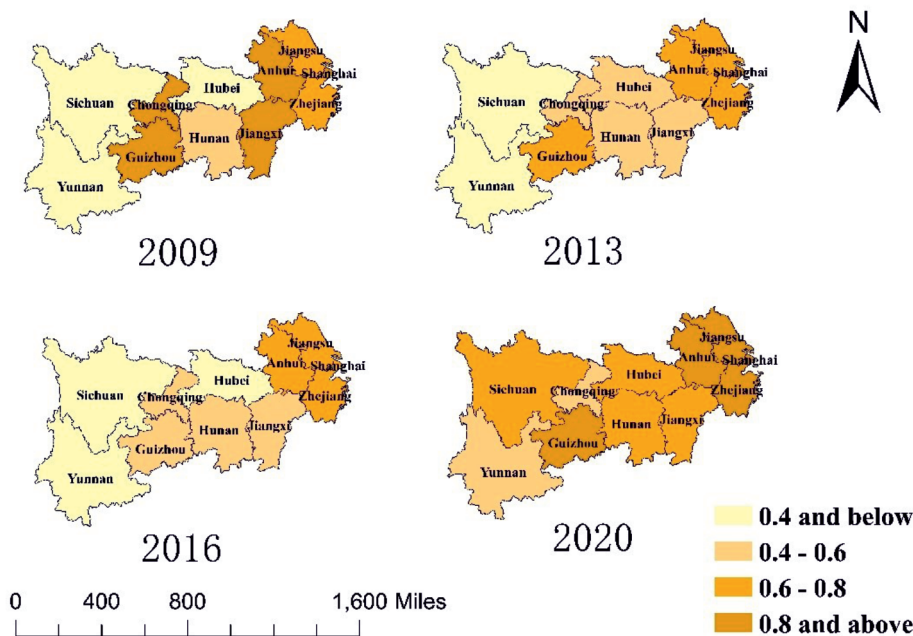


Fig. 8. Spatial evolutionary distribution of logistics efficiency along the Yangtze River Economic Belt.

of the Yangtze River Economic Belt is increasing. However, even the logistics efficiency of upstream provinces is relatively low, the GML_t^{t+1} , GEC_t^{t+1} and GTC_t^{t+1} are making rapid progress. The GML_t^{t+1} reached 1.484 in 2018-2019, and the average reached 1.029, which has exceeded midstream provinces and gradually approached downstream provinces. The average GTC_t^{t+1} of upstream provinces is 0.998, but it began to exceed 1 in 2016-2017. The midstream and downstream have no significant fluctuation on the whole, but the GTC_t^{t+1} is higher than GEC_t^{t+1} in recent years, which means the technical level shows an upward trend and becomes an important driving force for countries along the line to improve their sustainable development level.

During the research period, The GML index of most provinces and cities is higher than 1. It is noteworthy that the average GML_t^{t+1} of Sichuan province reached 1.083 and ranked first, which is also the main reason why the upstream provinces come from behind. And Sichuan is followed by Jiangsu, Hubei and Hunan, which are 1.059, 1.047 and 1.045 respectively, as shown in Table 3.

Anti-driving Effect of Environmental Regulation on Logistics Efficiency

Based on existing research, this paper divides environmental regulation into formal and informal environmental regulation as primary explanatory

Table 2. GML index and decomposition of logistics industry along the Yangtze River Economic Belt.

Year	GML_t^{t+1}	GEC_t^{t+1}	GTC_t^{t+1}
2009-2010	0.936	1.016	0.921
2010-2011	0.950	1.004	0.950
2011-2012	1.214	1.058	1.158
2012-2013	0.807	1.068	0.755
2013-2014	1.004	0.986	1.018
2014-2015	0.955	1.021	0.935
2015-2016	0.975	0.986	0.992
2016-2017	1.002	0.995	1.010
2017-2018	1.066	1.022	1.045
2018-2019	1.367	1.110	1.248
2019-2020	1.044	0.990	1.070
Avg.	1.029	1.023	1.009

Table 3. Average GML index and decomposition results from the provincial perspective.

Province	GML_t^{t+1}	GEC_t^{t+1}	GTC_t^{t+1}
Anhui	1.010	0.991	1.020
Guizhou	1.033	1.000	1.033
Hubei	1.047	1.052	0.995
Hunan	1.045	1.047	0.998
Jiangsu	1.059	1.000	1.057
Jiangxi	0.993	1.000	0.993
Shanghai	1.012	1.001	1.011
Sichuan	1.083	1.076	1.004
Yunnan	1.042	1.080	0.996
Zhejiang	1.038	1.003	1.038
Chongqing	0.959	1.003	0.960
Avg.	1.029	1.023	1.009

variables. After that, the panel regression model is then constructed for empirical analysis by controlling other variables related to logistics efficiency.

This paper uses provincial level data from the Yangtze River Economic Belt from 2009 to 2020, including 11 provinces and cities, to ensure data availability. The data used are all from China Statistical Yearbook, China Statistical Yearbook on Environment and Ecology, Environment Statement of each province and National Bureau of Statistics and China Economic Network databases.

Table 4 shows a descriptive statistical analysis of each variable. In general, the preliminary observation index data is relatively stable, with low deviation and insignificant fluctuation.

The autocorrelation test, heteroscedasticity test, and interface correlation test are used to analyze panel data.

All three tests, as shown in Table 5, reject the original hypothesis. As a result, the fixed effects model is employed in the analysis.

Table 6 displays the results of the fixed effect model analysis. The impact of formal environmental regulation on logistics efficiency along the Yangtze River Economic Belt is represented by Model 1. According to the findings, the intensity of formal environmental regulation is positively related to logistics industry efficiency and has passed the 1% significance test. The “innovation compensation effect” generated by formal environmental regulation exceeds the “crowding out effect”, forming a significant backward forcing effect, indicating that formal environmental regulation has a significant driving effect on the logistics efficiency. Hence, the H1. is verified. The model 2 examines the impact of informal environmental regulation on logistics

	Upstream			Midstream			Downstream		
	GML_t^{t+1}	GEC_t^{t+1}	GTC_t^{t+1}	GML_t^{t+1}	GEC_t^{t+1}	GTC_t^{t+1}	GML_t^{t+1}	GEC_t^{t+1}	GTC_t^{t+1}
2009-2010	0.906	1.033	0.875	0.890	1.017	0.874	1.000	0.999	1.002
2010-2011	0.953	1.055	0.905	0.938	1.004	0.934	0.956	0.952	1.008
2011-2012	1.257	1.038	1.217	1.253	1.144	1.119	1.142	1.013	1.129
2012-2013	0.768	1.126	0.678	0.833	1.027	0.809	0.826	1.041	0.792
2013-2014	0.969	0.964	1.006	0.995	0.996	0.999	1.045	1.000	1.044
2014-2015	0.955	1.053	0.905	0.991	1.006	0.985	0.929	1.000	0.929
2015-2016	0.968	0.978	0.996	0.984	0.983	1.000	0.976	0.995	0.981
2016-2017	1.001	0.954	1.054	1.032	1.050	0.984	0.981	0.993	0.987
2017-2018	1.065	1.060	1.010	1.043	0.994	1.049	1.084	1.005	1.078
2018-2019	1.484	1.251	1.225	1.342	1.071	1.253	1.268	0.999	1.267
2019-2020	0.994	0.926	1.108	1.010	1.074	0.942	1.120	0.990	1.129
Avg.	1.029	1.040	0.998	1.028	1.033	0.995	1.030	0.999	1.032

Fig. 9. GML index and decomposition results from the perspective of watershed.

Table 4. Descriptive statistical analysis.

Variable	Obs	Mean	Std. Dev.	Min	Max
LE	132	.645	.224	.289	1.084
FER	132	.452	.433	.011	2.162
INER	132	.247	.163	.118	.881
lnpgdp	132	10.735	.558	9.289	11.963
gov	132	.006	.002	.002	.014
info	132	.471	.157	.16	.8
tran	132	.131	.051	.054	.252
agg	132	1.054	.858	.443	4.513

Table 5. Model selection test.

Autocorrelation test	Prob > chi2	0.0000
Heteroscedasticity test	Prob > chi2	0.0000
Interface correlation test	Prob > chi2	0.0022

efficiency along the Yangtze River Economic Belt. For every 1% increase in intensity, logistics efficiency will increase by 0.126% and has also passed the 1% significance test. The H2a. is verified.

The coefficient direction of the control variables does not change significantly in either model. Consider model 1, where the degree of government intervention is significantly positive. This means that, in addition to relying on the market’s leadership, the development of the regional logistics industry necessitates government intervention and management in order to avoid market

Table 6. Panel regression results.

Explanatory variables	(Model 1) FER	(Model 2) INER
FER	0.0433*** (7.58)	
INER		0.126*** (5.59)
lnpgdp	-0.959*** (-34.59)	-0.939*** (-21.58)
gov	0.114*** (19.10)	0.133*** (15.18)
info	0.0850** (2.59)	0.0161 (0.29)
tran	0.134 (1.71)	-0.00297 (-0.03)
agg	-0.635*** (-80.18)	-0.628*** (-39.69)
_cons	0.0987*** (24.32)	0.0986*** (17.74)

Note: * p<0.05, ** p<0.01, *** p<0.001

failure and economic downturn. According to the dynamic logistics efficiency analysis in Fig. 8 and Fig. 9, the progress of logistics efficiency in upstream provinces in recent years has benefited to some extent from the government’s support for the west. The informationized level has a marginally positive impact on logistics efficiency. The improvement of the information environment can effectively alleviate the repeated transportation and waste of resources caused by information asymmetry, and promote the coordinated operation of the upstream and downstream of the

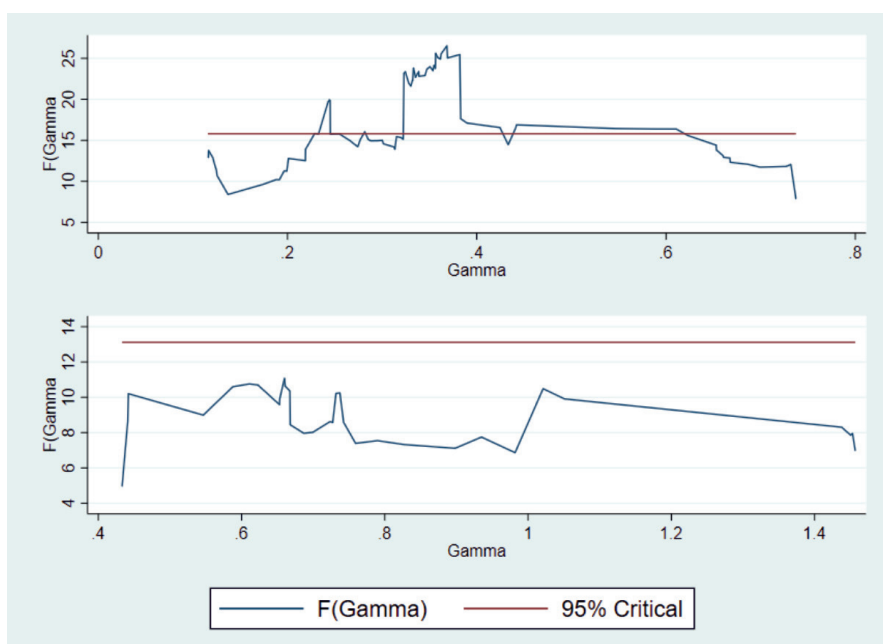


Fig. 10. F-test for formal environmental regulation threshold linearity results.

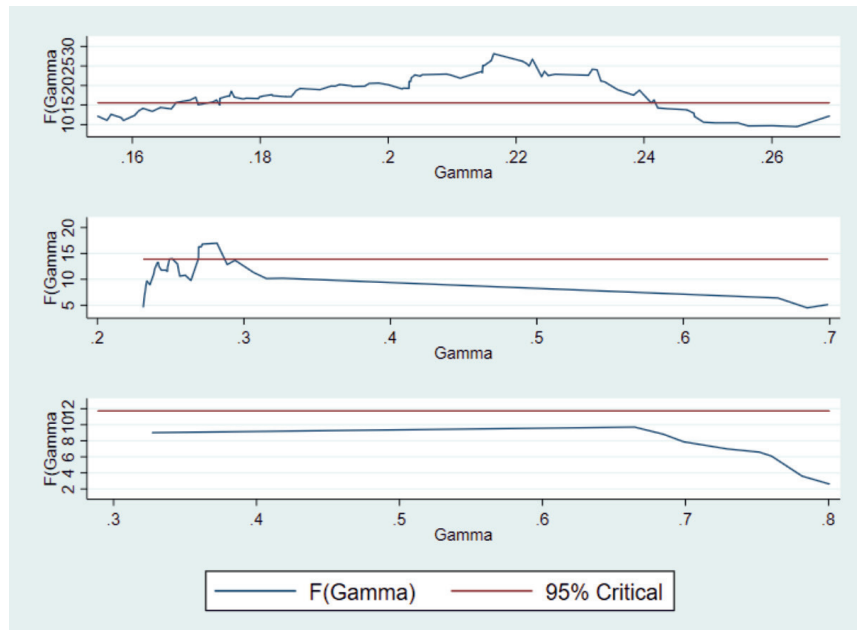


Fig. 11. F-test for informal environmental regulation threshold linearity results.

Table 7. F-test results.

Threshold variables	Threshold amount	Bootstrap Rep.	Trimming Per.	F-Value	P-Value
FER	Single	5000	0.15	26.5196***	0.0000
	Double	5000	0.15	11.0720	0.2066
INER	Single	5000	0.15	28.1329***	0.0000
	Double	5000	0.15	16.9807***	0.0044
	Triple	5000	0.15	9.7085	0.3192

Note: * p<0.05, ** p<0.01, *** p<0.001

supply chain. But at the same time, as China’s logistics efficiency is spatially high in the east and low in the west, some regions are still dominated by traditional logistics enterprises, and the level of informatization is not high, so the impact of informatization level on logistics efficiency is not obvious.

Threshold Effect of Environmental Regulation on Logistics Efficiency

Based on the panel regression results, environmental regulation reduces logistics efficiency along the

Table 8. Threshold estimation results.

Threshold variables	Threshold estimation	95% confidence interval
FER	$\gamma_1 = 0.3684$	[0.3684, 0.3684]
INER	$\theta_1 = 0.2217$	[0.2148, 0.2411]
	$\theta_2 = 0.2817$	[0.2717, 0.2817]

Yangtze River Economic Belt. According to Hansen (1999), the F-test is used before applying the panel threshold regression model to determine whether there is a threshold effect between variables for subsequent

Table 9. Threshold regression results.

Explanatory variables	(Model 1) FER	(Model 2) INER
FER · I(FER ≤ 0.3684)	6.0581*** (1.10)	
FER · I(FER > 0.3684)	2.819* (1.46)	
INER · I(INER ≤ 0.2217)		6.0864*** (1.21)
INER · I(0.2217 < INER ≤ 0.2817)		1.885 (1.51)
INER · I(INER > 0.2817)		-6.610* (3.04)

Note: * p<0.05, ** p<0.01, *** p<0.001

threshold quantity determination. The F-test results are shown in Table 7.

The test results shows that both formal and informal environmental regulation have significant threshold effect on the logistics efficiency along the Yangtze River Economic Belt. When formal environmental regulation is used as threshold variable, the F-Value of single threshold passes the 1% significance test (i.e. $P\text{-Value} < 0.01$), but double threshold fails. When informal environmental regulation is used as threshold variable, the F-Values of both single and double threshold pass the 1% significance test, but not the triple threshold. Therefore, with the change of formal environmental regulation intensity, formal environmental regulation has a single threshold effect on the logistics efficiency, whereas informal environmental regulation has a double

threshold effect on the logistics efficiency. The F-test for threshold linearity results are shown in Fig. 10 and Fig. 11, and the test rejects the original assumption of linearity if F sequence exceeds critical value.

Table 8 displays the threshold estimation results after determining the number of thresholds. It primarily reports the parameters of the single threshold model with formal environmental regulation as the threshold variable, the double threshold model with informal environmental regulation as the threshold variable and the corresponding 95% confidence interval, proving that the threshold value is true and effective.

Based on the above research, the threshold regression is applied. The regression results are shown in Table 9, and the likelihood ratio sequences are shown in Fig. 12 and Fig. 13.

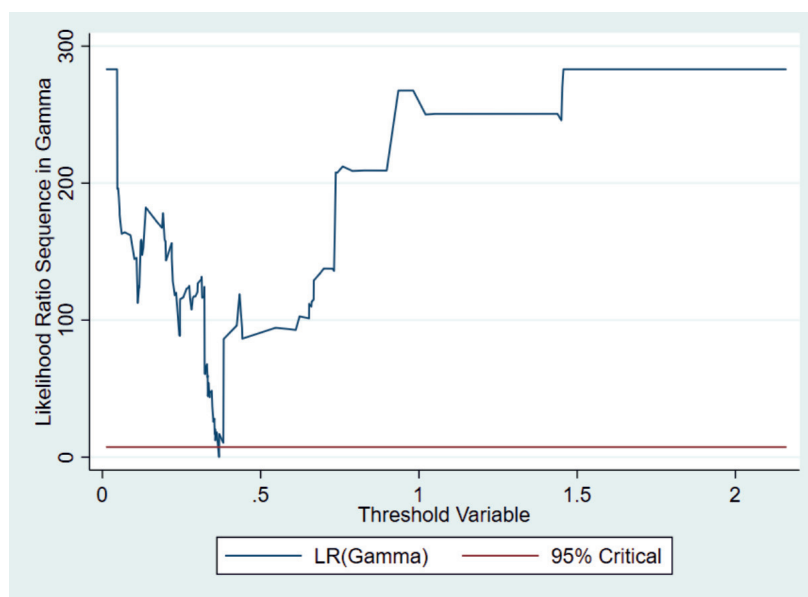


Fig. 12. Formal environmental regulation threshold likelihood ratio sequence.

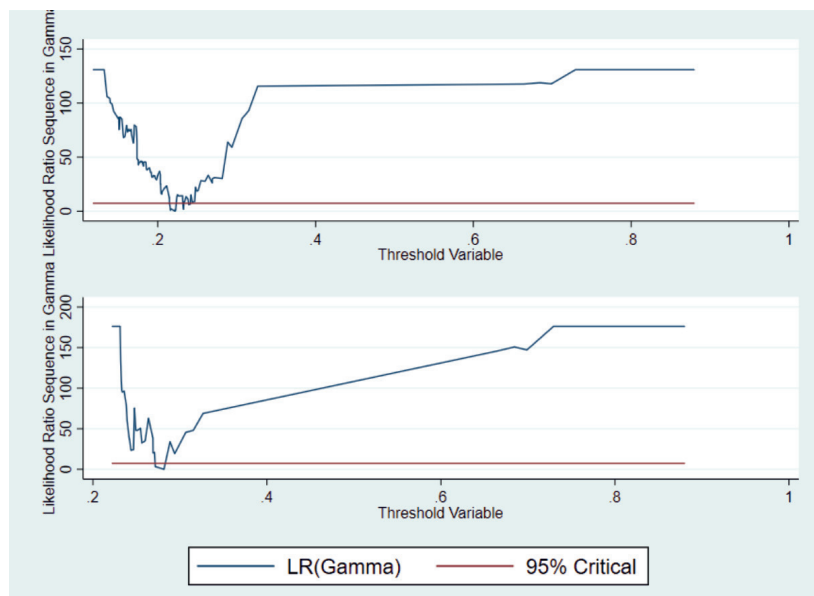


Fig. 13. Informal environmental regulation threshold likelihood ratio sequence.

Table 9 shows that the effect of environmental regulation on logistics efficiency varies significantly along the Yangtze River Economic Belt at different intervals. From model 1, when the intensity of formal environmental regulation is in the low range ($FER \leq 0.3684$), the regression coefficient is 6.0581 and passes the 1% significance test. When it reaches the high range ($FER > 0.3684$), the regression coefficient decreases to 2.819 and passes the 10% significance test. The H3. is verified.

From model 2, when the intensity of informal environmental regulation is in the low range ($INER \leq 0.2217$), the regression coefficient is 6.0864 and passes the 1% significance test. When it is in the middle range ($0.2217 < INER \leq 0.2817$), the regression coefficient drops to 1.885 and fails the significance test. When it get into the high range ($INER > 0.2817$), the regression coefficient decreases to -6.610 and passes the 10% significance test. The H4. is verified.

Conclusions and Recommendations

Conclusions

The study found that the overall logistics efficiency along the Yangtze River Economic Belt was not high during the study period and was susceptible to the regulatory and market environment. The spatial distribution of logistics efficiency shows a pattern of “high in the east and low in the west” from the perspective of the river basin. In recent years, the provinces have gradually improved logistics efficiency. By 2020, Shanghai, Anhui, Guizhou and Zhejiang will achieve super-efficient development. The GML index shows that the overall logistics efficiency along the “Belt and Road” is fluctuating upward. After 2015, technological progress became the primary driver of growth. Only Jiangxi and Chongqing have a provincial average GML index below 1, owing to the insufficient effect of technological progress and the urgent need to break through the bottleneck of logistics technology.

Futhermore, both formal and informal environmental regulation, with informal environmental regulation having a greater impact, can positively drive logistics efficiency. This implies that in the case of a dual overlap of demand counter-driven and external constraint effects, external constraints may play a more significant role. Both types of regulation exhibit threshold effects at the same time. At different levels of environmental regulation, the effects on logistics efficiency will be different. Other influencing factors point to the importance of government intervention and information in improving logistics efficiency.

Recommendations

The role of traditional factor-driven and investment-driven models in improving logistics efficiency has

weakened in the context of the “new normal” economy. To overcome the barrier of extensive development mode to logistics efficiency, logistics enterprises must find new growth points. Based on the findings presented above, this paper makes the following two policy recommendations.

(i) Enhance formal environmental regulation to foster the innovation compensation effect. To better stimulate the countervailing force, the government should make corresponding changes to the existing environmental regulations in the logistics industry, so that environmental regulations become a new driving force for technological innovation in logistics enterprises.

(ii) Guide the public in rationally participating in environmental protection, effectively serving as “demand-driven external constraints”. To positively influence the greening of the logistics industry, the government must strengthen the environmental regulation and governance system while also utilizing informal environmental regulation.

This paper examines the effect of environmental regulations on the efficiency of the logistics industry in the Yangtze River Economic Belt based on existing literature and theories, but there are some areas for further research.

(i) Because carbon emission data is readily available in the logistics industry, the empirical process of this paper relies on data at the provincial level of the Yangtze River Economic Belt and does not go deeper into the municipal level.

(ii) Since the official data of some indicators for 2021 have not been published or stopped, the research period of this paper is only up to 2020. Later, we can broaden the data collection channels and conduct research at a more micro level to improve the accuracy of the findings.

(iii) Due to significant changes in the statistical caliber of the yearbook and the difficulty of quantifying policy provisions, this paper's measurement of formal environmental regulation focuses on the effect of governance, which has some limitations.

Future studies can try to build a more comprehensive indicator system to reflect the level of formal environmental regulation from multiple perspectives with the improvement of government data disclosure. Furthermore, more scientific and objective data can be used to study the relationship between environmental regulation and logistics efficiency in China from the standpoint of a more refined decision-making unit, allowing for more scientific policy recommendations and theoretical guidance for regional environmental regulation and logistics efficiency.

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Conflict of Interest

The authors declare no conflict of interest.

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