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Environmental information disclosure, market competition, and green transformation: evidence from Chinese heavily polluting listed companies

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Abstract
With the further deterioration of the global ecological environment and increased market competition, promoting the green transformation (GT) of heavily polluting companies with high consumption and emissions, and environmental damage has been an inevitable trend in green development. The public is becoming increasingly concerned about whether environmental information disclosure (EID) can drive the green transformation of heavy polluters. Based on the annual data of A-share listed companies with heavily pollution from 2011 to 2020, this study scores EID according to 30 environmental disclosure indexes (total 30 points) and investigates nonlinear regression to examine the impact of EID on GT and the moderating effect of market competition. Research has found a positive U-shaped relationship between EID and GT. When the level of EID exceeds 3 points (inflection point), it will have a positive impact on GT. Market competition flattens the positive U-shaped relationship, and the inflection point shifts to the right. The inflection point for EID rises from 3 to 4. The mean level of EID of heavy polluters is close to 7, which is low overall. However, most of the them have already exceeded the inflection point. This study provides new literature and perspectives on the nonlinear relationship between EID and GT. The findings provide intrinsic motivation for managers to take the initiative in EID and are also relevant for promoting the green transformation of heavy polluters, government regulation of the market, and sustainable human development.

Keywords Environmental information disclosure · Green transformation · Green innovation · Market competition · Heavily polluting companies · U-shaped

JEL Classification C12 · I18 · L51

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1 Introduction

The Intergovernmental Panel on Climate Change has released a report that global surface temperatures between 2011 and 2020 have risen by 1.09 °C compared to the industrial revolution, of which approximately 1.07 °C was attributed to human activities. This has led to an increasing frequency of extreme weather events. In 2020, Rockstrom pointed out that mankind will face a critical point in the ecological environment, and that the next 10 years will be a crucial period to change the deterioration of the ecological environment. In addition to climate change, scholars have studied the effects of environmental pollution on soil (Turan et al., 2019; Zhou et al., 2020). They found that heavy metals such as lead (Turan, 2020), cadmium (Zheng et al., 2020), nickel (Turan, 2021, 2022), and hydrargyrum (Xiang et al., 2021) negatively affect soil health as well as crop quality, which directly contribute to serious health problems in humans and animals (Turan, 2019). Turan et al. (2019) and Iqbal et al. (2023) found that biochar and magnesium–potassium phosphate cement, among others, can reduce plant uptake of heavy metals. It can be seen that the disadvantages brought to mankind by environmental pollution are endless. Only by insisting on the harmonious coexistence of man and nature is the basic guideline for global economic development (Alvarado et al., 2022). Currently, an emerging topic of public concern is the manner in which the relationship between environmental protection and economic development should be dealt with to achieve a positive interaction. This was the motivation for the research undertaken in this study.

From the ancient Eastern Zhou Dynasty, China has been promoting "the rules of nature and uniting human and universe" to the modern 20th National Congress report, which proposes "promoting green development and harmonious coexistence between humanity and nature." China has emphasized the importance of respecting, responding to, and protecting nature. In the past 40 years, China's economy has grown violently. However, this rough economic development model has eventually led to the continuous destruction of the environment (Minh Ha et al., 2023). Heavily pollution companies are the primary producers of environmental pollution. Because of its high consumption, emissions, and environmental damage, it is the focus of China's green development (Li et al., 2023). Promoting the green transformation (GT) of heavily polluting companies is of great value in realizing green and sustainable development in China.

Exploring the path of sustainable development has always been a persistent goal of humankind (Hristov & Chirico, 2023). Scholars from different countries have found that environmental and governance performance is negatively related to financial performance in Indian Nifty50 firms (Rao et al., 2023). Environmental, Social, and Governance (ESG) is an indicator that can be used to evaluate a firm's sustainability capabilities (Ahmad et al., 2023). ESG not only increases the enterprise value and financial performance of the US companies (Habib, 2022; Habib & Mourad, 2023), but also reduces the likelihood of financial distress (Habib, 2023). The implementation of environmental management accounting has positively affected organizational performance in large manufacturing firms in Indonesia (Sari et al., 2021). This shows that having excellent environmental performance has a positive impact on the sustainability of companies in many countries. Environmental information, an important public information for governance companies' green innovation, plays a vital role in supporting environmental sustainability, promoting the efficient use of resources, and guiding companies to pay attention to environmental protection (Prasad et al., 2017). As an important way for the government and the public to supervise the environmental

behavior of companies, EID is of great significance in promoting the implementation of their environmental responsibility. China's new Environmental Protection Law was enacted in 2015. For the first time, heavily polluting companies were required to disclose basic and emission information in the form of legislation. The Administrative Measures for the Legal Disclosure of Enterprise Environmental Information, implemented in 2022, also requires key emission units to disclose eight types of environmental information, including environmental management and pollutant generation. This indicates that China is paying increasing attention to heavily polluting companies' EID. Due to the continuous improvement of laws and regulations on environmental protection issues, companies face multiple pressures from the government and the public. This forces the management to pay more and more attention to corporate environmental management.

Affected by the deterioration of the global environment, the international competitive situation intensified, as did market competition (MC). Market competition, as an external governance mechanism, mainly influences companies' decisions and behaviors through interaction with their internal governance system. Due to the influence of market competition, the average resource allocation ratio of the industry is reduced. The market will manage the resource allocation of companies more strictly. In addition, with the growth of competitors in the market, the disclosure risk factor increases when firms disclose information externally (Luo et al., 2022).

In summary, this study examined the following questions:

RQ1. Can EID promote GT among Chinese heavy polluters?
RQ2. How does EID affect the GT?
RQ3. What is the impact of EID on firms' GT under different intensities of market competition?

Based on the annual data of A-share listed companies with heavily pollution from 2011 to 2020, this study investigates nonlinear regression to examine the impact of EID on GT and the moderating effect of market competition. It aims to explore the effective way of human sustainable development. The contributions of this paper are shown below: First, this paper finds a positive U-shaped relationship between EID and GT. When the level of EID exceeds 3 points, there is a positive relationship with GT. This provides new literature and perspectives on the nonlinear relationship between EID and GT. Second, based on transaction cost theory, signaling theory, and market pressure hypothesis, this study analyzes that the effects of EID on GT are dissected from three aspects: cost, resources, and supervision effects. It improves the strong theoretical support for the article and helps to deeply understand the economic benefits generated by EID, thus stimulating the intrinsic motivation of companies to improve the level of EID. Third, this study explores effective green transformation methods for heavily polluting companies, which can promote the benign interaction between environmental protection and economic development, and help China and the world achieve sustainable development of the green economy. Finally, the study found that market competition makes the U-shaped relationship between EID and GT flatter, with the inflection point of EID to rise from 3 to 4 points. This suggests that fierce market competition is not conducive to companies achieving green transformation. The finding provides data support for the implementation of market competition strategies by heavily polluting companies.

2 Literature review

2.1 Environmental information disclosure and green transformation

Green transformation is a major proposition for sustainable socio-economic development. Many scholars have studied the environmental and economic benefits of green innovation. It is found that green innovation not only promotes the consumption of renewable energy (Zhang et al., 2022), but also reduces carbon emissions and atmospheric pollution (Obobisa et al., 2023; Zhao et al., 2023). Green innovation can also bring positive impacts on enterprise sustainable development (Agyemang et al., 2021; Minh Ha et al., 2023) and green economic benefits (Ren et al., 2023). With regard to exploring effective ways of green transformation, scholars have researched a variety of aspects such as external stakeholders and social activities (Jiang et al., 2023; Mo et al., 2022). Some scholars have found that ESG can promote green innovation in firms (Wang et al., 2023). ESG is a comprehensive score based on a firm's environmental, social, and governance, which is an indicator that can be used to evaluate a firm's sustainability capabilities (Ahmad et al., 2023). However, few studies have singled out the impact of environmental information on green innovation.

According to the international development trend, investors will have more trust in the investment strategies of companies for "environmental protection and environmental governance." Disclosing more comprehensive environmental information can help companies to alleviate problems such as information asymmetry (Li et al., 2023), improve energy efficiency (Wang & Shao, 2023), promote the development of regional green finance (Hou et al., 2023), increase the value of companies (Pedron et al., 2021), improve the financial performance of banks (Xi et al., 2022), and provide regional green total factor productivity (Zhao & Chen, 2022).

2.2 Market competition

Market competition (MC) is an external governance mechanism. As market competition increases, some scholars believe that water disclosure will rise and then fall (Zhou et al., 2020), while others believe that companies will disclose less information (Luo et al., 2022).

There are generally four views in the academic community about the impact of MC and enterprise innovation. First, there is a positive effect of MC on firms' innovation. Arrow (1972) argues that innovation can help firms to achieve cost competitive advantage in the competition and make innovative profits, which, in turn, will promote managers to accelerate the pace of innovation. Yan et al. (2022) argued that competition improves the overall quality of innovation by improving the allocation of innovative resources. Competition has a positive impact on new product development (Dagar & Malik, 2023). Second, the MC has a negative impact on firms' innovation. Schumpeter (1942) argued that substantial investment is required to carry out corporate innovation activities. Therefore, in the competition, whether to choose long-term or short-term benefits, many management will choose the latter (Guo et al., 2022). Excessive competition will negatively affect innovation speed (Briest et al., 2020), green innovation (Im et al., 2015), and innovation efficiency (Shi & Shen, 2022). Third, there is a nonlinear positive U-shaped relationship between MC and firm innovation (Huang & Chen, 2022). Meza-Gonzalez and Sepulveda (2019) conclude that there is a positive U-shaped relationship between foreign competition and innovation

among Mexican manufacturing firms. Finally, some scholars found an inverted U-shaped relationship between MC and corporate innovation (Suzuki, 2020).

In summary, this paper summarizes recent references on environmental disclosure, market competition, and green transformation, as shown in Table 1.

3 Theoretical, conceptual framework, and hypothesis

3.1 Environmental information disclosure and green transformation

Based on transaction cost theory, signaling theory, and market pressure hypothesis, this study analyzes that the effects of EID on GT are dissected from three aspects: cost, resources, and supervision effects. Environmental information is a kind of publicly disclosed information with green development attributes and is currently in the transition stage from voluntary to mandatory disclosure. Companies have a certain degree of autonomy in EID (Prasad et al., 2017). Green innovation focuses on ecological environmental protection and sustainable development, also known as eco-innovation or environmental technological innovation, and refers to new technologies for energy conservation, pollution control, and green services (Sun et al., 2020). Green innovation is characterized by large

Table 1 Recent literature on environmental information disclosure, market competition, and green transformation

Environmental information disclosure (EID)	EID can increase company value (Pedron et al., 2021)
	EID improves financial performance of banks (Xi et al., 2022)
	EID improves regional green total factor productivity (Zhao & Chen, 2022)
	EID reduces information asymmetry (Li et al., 2023)
	EID improves energy efficiency (Wang & Shao, 2023)
	EID can facilitate the development of green finance (Hou et al., 2023)
Green transformation (GT)	Green innovation (GI) can contribute to sustainable business development (Agyemang et al., 2021; Minh Ha et al., 2023)
	GI promotes renewable energy consumption (Zhang et al., 2022)
	Fulfilling social responsibility promotes GI (Jiang et al., 2023; Mo et al., 2022)
	GI increases green economic benefits (Ren et al., 2023)
	GI can reduce carbon emissions (Obobisa et al., 2023; Zhao et al., 2023)
	ESG can promote GI (Wang et al., 2023)
Market competition (MC)	MC is negatively correlated with innovation (Briest et al., 2020; Im et al., 2015; Schumpeter, 1942; Shi & Shen, 2022)
	MC and innovation are positively correlated (Arrow, 1972; Dagar & Malik, 2023; Yan et al, 2022)
	A positive U-shaped relationship between MC and GI (Huang & Chen, 2022; Meza-Gonzalez & Sepulveda, 2019)
	An inverted U-shaped relationship between MC and firm innovation (Suzuki, 2020)
	MC is negatively related to corporate disclosure (Luo et al., 2022)
	MC can inspire short-sighted behavior in management (Guo et al., 2022))

EID Environmental information disclosure; *GT* Green transformation; *MC* Market competition; *GI* Green innovation; and *ESG* Environment, social, and governance

capital requirements, long cycles, and high uncertainty, as the management is relatively cautious in making relevant decisions (Xiao et al., 2019).

First of all, the transaction cost theory suggests that firms incur information creation, transmission, and proprietary costs when disclosing information (Lu et al., 2020). The EID increases the cost of business investment in pollution abatement and environmental protection (Gao et al., 2023), and environmental information transfer and proprietary costs (Hermalin & Weisbach, 2012). These costs can crowd out some of the resources of the company. Secondly, according to the signaling theory, EID can send a signal to society that the company attaches importance to environmental protection (Kuo et al., 2015), which helps stakeholders to have a comprehensive understanding of the firm's environmental performance and to judge its future sustainability (Lin, 2022). At the same time, it can also help companies establish a good social image in the market, enhance the reputation capital, and reduce the cost of obtaining external financing for themselves (Luo et al., 2019), which has a resource effect on the company. Finally, the market pressure hypothesis suggests that information intermediaries generate public influence, creating significant pressure on firms, which, in turn, monitors managerial behavior and has a supervisory effect on firms (Chai et al., 2022). EID can also demonstrate the level of corporate governance and help external stakeholders to monitor management from all angles (Liu et al., 2023). This, in turn, urges management to emphasize EID.

Therefore, when corporate EID is limited, valuable information cannot be conveyed to external stakeholders. The negative impact of the cost effect is much higher than the positive impact of resource and monitoring effects, which will have a negative impact on the green transformation of companies. With the increasing content of EID, the technical proficiency of companies in EID increases and the efficiency of EID improves. The more the disclosure content increases, the more it can reduce market asymmetry. The positive impact of the resource and supervision effects will be higher than the negative impact of the cost effect, and companies' green transformation will be promoted faster.

Combining the above literature and theoretical analysis, the hypotheses of this paper are as follows.

H1 Environmental information disclosure has a positive U-shaped relationship with green transformation of heavily polluters.

3.2 Environmental information disclosure, market competition, and green transformation

This study will explore the moderating effects arising from market competition through the cost competitive advantage and Schumpeter hypothesis. As an external governance mechanism, market competition can have a significant impact on firm managers' behavioral decisions (Gaan et al., 2023). Firms with competitive advantages within their industries have greater flexibility and resilience in the face of unexpected external shocks. Modern firms' competitive advantages rely on their low costs and differentiation (Le & Lei, 2018).

The cost competitive advantage hypothesis argues that two problems cannot be ignored in the pursuit of profit maximization by companies: the cost of information disclosure and the risk of information leakage (Plecnik et al., 2022). On the one hand, environmental protection and governance is a capital-intensive and high-risk expenditure (Ma et al., 2022). With the intensification of market competition, the average resource allocation ratio of the industry has decreased. Companies seek to maximize profits and take advantage of cost

competition. They tend to compress the cost of producing environmental information, leading to a reduction in the amount of EID (Luo et al., 2022), a decline in the quality of disclosure (Verrecchia & Weber, 2006), and the level of voluntary disclosure (Lee & Lee, 2022). On the other hand, highly competitive markets have more homogeneous companies. Revealing more relevant information from competitors may increase the risk of information disclosure to companies and impair competitive advantages (Yen et al., 2016). Fierce market competition increases the financial and company risks of companies, and the requirement for the reasonableness of enterprise resource allocation is higher. It is difficult to improve environmental management if companies are constrained by resources (Tsendsuren et al., 2021). Firms in highly competitive industries can avoid the risk of predation by competitors by disclosing less information (Verrecchia, 1983) or adopting some risk management strategies (Di Vaio et al., 2023). Based on the rational economic person assumption, firms may reduce environmental disclosure to minimize disclosure risk and gain greater benefits. Moreover, the more competitive the market is, the more investors demand higher quality of inventions (Thompson & Woerter, 2020). The demand for high-quality environmental information disclosure leads to a shift of the inflection point to the right.

The Schumpeterian hypothesis suggests that firms require large investments to carry out innovative activities, and that only firms with a strong market position can provide a constant flow of funds for innovation. Thus, the MC has a negative impact on firms' innovation (Schumpeter, 1942). Moreover, corporate managers driven by economic interests are more willing to allocate funds to economic projects, reducing green innovation (Guo et al., 2022). This suggests that market competition can have a negative impact on a firm's green innovation.

This shows that market competition may stimulate managers to continue the crude development model and the short-sighted behaviors that seek benefits at the expense of the environment. However, to strive for a cost competitive advantage, companies should consider reducing the cost of EID, that is, curtailing environmental protection costs, resulting in less environmental information to disclose. They must also consider reducing the risk of information leakage, and the motivation for EID decreases. This eventually leads to a reduction in corporate EID, reduces the pace of green transformation of companies, and the inflection point shifts to the right. Combining the above literature and theoretical analyses, the hypotheses of this paper are as follows.

H2 Market competition makes the positive U relationship between environmental information disclosure and the green transformation of heavily polluters smoother, and the inflection point shifts to the right.

The research framework is shown in Fig. 1.

4 Methodology

4.1 Data source and processing

China's CO2 emissions and gross domestic product (GDP) have been increasing every year from 2011 to 2020. In 2020, these two items rank first and second in the world, respectively, and high-carbon emitting companies are mainly located in heavy polluting

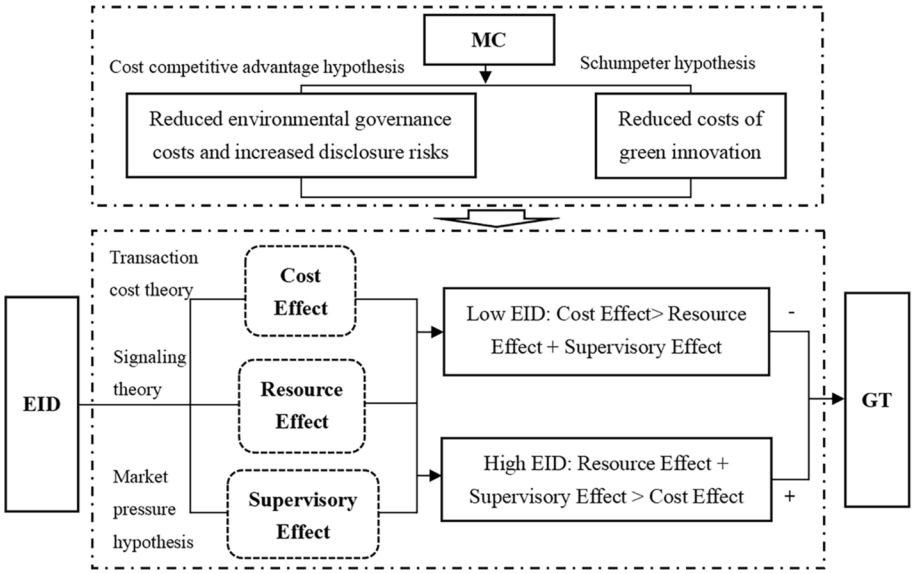

Fig. 1 Relationship between environmental information disclosure, market competition, and green transformation of heavily polluters

industries. Based on this, this study selected a sample of Chinese A-share listed companies experiencing heavily pollution from 2011 to 2020. Heavily polluted industries are recognized in accordance with the "Guidelines for Environmental Information Disclosure of Listed Companies" issued by the Ministry of Environmental Protection (MEP) in 2010, and the "Industry Classification Guidelines for Listed Companies" revised by the China Securities Regulatory Commission (CSRC) in 2012. All data were obtained from the CSMAR (China Stock Market & Accounting Research Database) and CNRDS (Chinese Research Data Services) databases. Green Innovation selects the data from period t+1. After eliminating companies with invalid and missing data, the study finally obtained 8028 observations.

4.2 Variable definition

4.2.1 Explained variable

Green Transformation (GT). This study examined green transformation from the perspective of green innovation in firms. The output of green innovation is green patents of firms. Therefore, the number of corporate green patents has become an important manifestation of corporate green transformation. Considering the various uncertainties between patent applications and their granting, we drew on existing research choose to use the number of green patent applications as a proxy variable for corporate green transformation (Bendig et al., 2022). In the baseline regression, we add 1 to the value of the enterprise's green patent applications and take the natural logarithm. Promoting the green transformation of heavily polluting companies as soon as possible is of great significance for sustainable economic development as well as environmental protection.

4.2.2 Explanatory variable

Environmental Information Disclosure (EID). This study evaluated the environmental information disclosures of sample companies using a content analysis method. EID data selected to the CSMAR's Environmental Research Database. This includes five aspects: environmental management, environmental regulation and certification, environmental performance and governance, environmental information disclosure vehicles, and environmental liabilities. Environmental information disclosure scores of the individual sample companies were obtained by summing the scores of the above five aspects; the specific scoring criteria are shown in Table 2. In the baseline regression, we added 1 to the total score of EID to perform natural logarithmic processing. EID has a positive impact on reducing market information asymmetry and promoting environmental sustainability.

4.2.3 Adjustment variables

Market Competition (MC). In this study, the Herfindahl index (HHI) is used to represent the degree of market competition; the closer HHI tends to zero, the more competitive the market. Proper market competition can bring crisis and motivation to the enterprise.

$$\mathrm{HHI} = \sum \left(\frac{X_i}{X} \right)^2 \tag{1}$$

where X_i is the income from main company of a company, X is the total income from main company of the industry to which the company belongs, and (X_i/X) is the company's industry market share. For consistency with other indicators, the opposite of the HHI is used to represent the competitive intensity of the market in this study.

4.2.4 Control variables

To exclude the influence of other variables on the results of the study, company value, company age, gearing ratio, total asset turnover ratio, earnings per share, nature of ownership, book-to-market value, management shareholding ratio, and first shareholder shareholding ratio were selected as control variables.

Table 3 lists the main variables and their calculations.

4.3 Model building

The following model was constructed in this study to empirically test the relationship between EID and GT to test the hypotheses:

$$GT_{i,t+1} = \alpha_0 + \alpha_1 EID_{i,t} + \alpha_2 EID^2_{i,t} + \alpha_3 Control_{i,t} + \tau_t + \mu_j + \varepsilon_{i,t} \tag{2}$$

In order to test the moderating effect of MC, the specific model is as follows:

$$GT_{i,t+1} = \alpha_0 + \alpha_1 EID_{i,t} + \alpha_2 EID^2_{i,t} + \alpha_4 MC_{i,t} + \alpha_5 EID_{i,t} * MC_{i,t} + \alpha_6 EID^2_{i,t} * MC_{i,t} + \alpha_7 Control_{i,t} + \tau_t + \mu_j + \varepsilon_{i,t} \tag{3}$$

$GT_{i,t+1}$ is the total green transition of company i at time t + 1, $EID_{i,t}$ is the level of environmental information disclosure of company i at time t, $MC_{i,t}$ is the intensity of market

Table 2 Scoring criteria for environmental information disclosure

Type of disclosure	Disclosures	Scoring instructions
Environmental management	Environmental philosophy and policy; Completion of environmental targets, future environmental targets; Develop relevant environmental management system, system; Participating environmental related education and training; Participate in special environmental protection activities and social welfare activities; Establish an emergency mechanism for major environmental emergencies; Honors or awards received in environmental protection; Implement the "three simultaneities" system	Total 20 items, each with a description of 1 point, no description of 0 points
Liabilities	Wastewater discharge; CO_D, CO_2, or SO_2 Emissions; Soot and dust emissions; Industrial solid waste discharge	
Performance and governance	Waste gas emission reduction treatment; Wastewater treatment; Dust and smoke management; Solid waste utilization and disposal; Control of noise, light pollution, radiation, etc.; Implementation of clean production	
Regulation and Certification	Whether listed companies disclose environment-related information in their annual reports; Whether the social responsibility report discloses information relating to the environment; Whether the environmental report is disclosed separately from the environmental report	Total 10 items. Each item is "Yes" scored 1 point, "No" scored 0 points; pass scores 1 point, fail scores 0 points
Information disclosure vehicles	Whether the key pollution monitoring units; Whether the pollutant emissions meet the standard; Whether the occurrence of major environmental pollution emergencies; Whether environmental violations occur; Whether the occurrence of environmental letters and visits; ISO14001 certification; ISO9001 certification	

Table 3 Main variables and calculation methods

Variables		Symbols	Description
Explained variables	Green Transformation	GT	Ln (Green patent applications + 1)
Explanatory variables	Environmental Information Disclosure	EID	Ln (Total rating of environmental information disclosure + 1)
Adjustment variables	Market Competition	MC	- HHI
	Company Value	TobinQ	Market Capitalization/Total Assets
	Company Age	AGE	Current year—year the company went public
	Gearing Ratio	LEV	Total liabilities/Total assets
	Total Assets Turnover Ratio	TAT	Operating income/Total assets ending balance
	Earnings Per Share	EPS	Net income/Weighted average total number of shares for the year
Control variables	Nature of Ownership	STA	1 for state-owned enterprises, otherwise 0
	Book-to-Market Value	BM	Total Assets/ Market values
	Management Shareholding Ratio	MO	Number of shares held by directors, supervisors, and senior management/Total number of shares
	First Shareholder Shareholding Ratio	Top1	Number of shares held by the first shareholder/Total number of shares

competition of company i at time t, $Control_{i,t}$ is the control variable at the company, τ_t represents year fixed, μ_j represents industry fixed, and $\varepsilon_{i,t}$ is a random error term.

5 Results

5.1 Descriptive statistics

From Table 4, the mean value of GT is 0.826 with a minimum value of 0 and a maximum value of 7.356. This suggests that there are large differences in GT between the samples, and the overall green development level is low. The maximum and minimum values of EID are 0 and 3.332, respectively, with a mean value is 2.069. When converted to the original total score, the minimum and maximum values were 0 and 27, respectively, with a mean value is close to 7, indicating that the level of EID of heavily polluters is low and uneven. The maximum and minimum values of MC are -0.0139 and -1, respectively, with large differences in MC. The statistics of other variables indicate that the sample of this study covers companies with different corporate characteristics.

5.2 Correlation analysis

From Table 5, the correlation coefficient between EID and GT is positive and significant. The correlation coefficient between MC and GT is negative and significant, which is in line with the expected hypothesis. In addition, the correlation coefficients of other variables are lower than the threshold value of 0.7 in the classical literature, indicating the absence of multicollinearity.

Table 4 Descriptive statistics

Variable	Obs.	Mean	Std. dev.	Min.	Max.
GT	8,028	0.826	1.112	0	7.356
EID	8,028	2.069	0.716	0	3.332
MC	8,028	−0.0910	0.0917	−1	−0.0139
TobinQ	8,028	2.085	2.936	0.699	118.3
AGE	8,028	16.83	7.486	2	32
LEV	8,028	0.433	0.768	0.00710	63.97
TAT	8,028	0.647	0.466	0.000188	8.787
EPS	8,028	0.404	0.816	−16.75	16.54
STA	8,028	0.397	0.489	0	1
BM	8,028	0.645	0.257	0.00850	1.430
MO	8,028	0.118	0.193	0	0.897
Top1	8,028	0.354	0.152	0.00290	0.900

EID Environmental information disclosure; *GT* Green transformation; *MC* Market competition; *TobinQ* Company value; *AGE* Company age; *LEV* Gearing ratio; *TAT* Total assets turnover ratio; *EPS* Earnings per share; *STA* Nature of ownership; *BM* Book-to-market value; *MO* Management shareholding ratio; and *Top1* First shareholder shareholding ratio

Table 5 Correlation analysis

Variables	GT	EID	MC	TobinQ	AGE	LEV	TAT	EPS	STA	BM	MO	Top1
GT	1											
EID	0.257***	1										
MC	−0.138***	−0.041***	1									
TobinQ	−0.112***	−0.147***	0.061***	1								
AGE	0.126***	0.021*	−0.106***	0.023**	1							
LEV	0.046***	0	−0.025**	0.467***	0.124***	1						
TAT	0.060***	0.087***	−0.090***	−0.00600	0.067***	0.025**	1					
EPS	0.091***	0.053***	0.049***	−0.0160	−0.125***	−0.146***	0.059***	1				
STA	0.222***	0.154***	−0.093***	−0.098***	0.522***	0.092***	0.059***	−0.071***	1			
BM	0.282***	0.241***	−0.149***	−0.457***	0.140***	0.050***	0.00300	−0.053***	0.278***	1		
MO	−0.131***	−0.122***	0.105***	−0.0170	−0.588***	−0.105***	−0.035***	0.109***	−0.484***	−0.115***	1	
Top1	0.186***	0.125***	−0.131***	−0.129***	−0.00800	−0.00800	0.072***	0.079***	0.235***	0.237***	−0.069***	1

***p-value < 1%; ** < 5%; and * < 10%; *EID* Environmental information disclosure; *GT* Green transformation; *MC* Market Competition; *TobinQ* Company value; *AGE* Company age; *LEV* Gearing ratio; *TAT* Total assets turnover ratio; *EPS* Earnings per share; *STA* Nature of ownership; *BM* Book-to-market value; *MO* Management shareholding ratio; and *Top1* First shareholder shareholding ratio

Table 6 Regression results of baseline regression and moderating effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variables	GT	GT	GT	GT	GT	GT	GT	GT	GT	GT
EID	−0.615***	−0.453***	−0.508***	−0.338**	−0.524***	−0.381***	−0.580***	−0.435***	−0.590***	−0.467***
	(0.0982)	(0.142)	(0.0943)	(0.137)	(0.0938)	(0.136)	(0.0932)	(0.135)	(0.0927)	(0.134)
EID^2	0.264***	0.188***	0.204***	0.134***	0.211***	0.144***	0.208***	0.144***	0.213***	0.151***
	(0.0252)	(0.0364)	(0.0243)	(0.0351)	(0.0241)	(0.0350)	(0.0238)	(0.0343)	(0.0237)	(0.0342)
MC		−0.149		−0.367		0.209		0.0781		0.631
		(1.017)		(0.978)		(0.971)		(0.956)		(0.949)
EID*MC		0.613		1.094		0.975		0.876		0.776
		(1.111)		(1.067)		(1.058)		(1.042)		(1.034)
EID^2*MC		−0.499*		−0.561**		−0.570**		−0.515**		−0.523**
		(0.277)		(0.267)		(0.264)		(0.260)		(0.258)
Control	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	No	No	No	No	Yes	Yes	No	No	Yes	Yes
Year	No	No	No	No	No	No	Yes	Yes	Yes	Yes
Constant	0.831***	0.743***	−0.117	−0.138	0.210*	0.0796	−0.507***	−0.486***	−0.186	−0.241
	(0.0874)	(0.127)	(0.106)	(0.139)	(0.117)	(0.150)	(0.109)	(0.140)	(0.119)	(0.150)
Observations	8,028	8,028	8,028	8,028	8,028	8,028	8,028	8,028	8,028	8,028
R-squared	0.079	0.100	0.163	0.174	0.182	0.190	0.205	0.213	0.221	0.228

***p-value < 1%; ** < 5%; and * < 10%; *EID* Environmental information disclosure; *GT* Green transformation; *MC* Market competition; *EID^2* The 2nd power of EID; *EID*MC* EID multiplied by MC; *EID^2*MC* The 2nd power of EID multiplied by MC; *Control* All control variables; *Industry* Fixed industry; and *Year* Fixed year

5.3 Baseline regression and moderating effects

Columns (1) and (3) of Table 6 represent the two models with and without control variables when industry and year are not fixed. Columns (5), (7), and (9) represent the three models when control variables are added, with a single fixed industry or year, and a double fixed year and industry. The regression results showed that the coefficients of EID^2 were 0.264, 0.204, 0.211, 0.208, and 0.213, which were significant at the 1% level. The U-test result was significant at the 1% level. The inflection point is calculated as 1.385 by column (9), and the environmental information disclosure score takes the value (2, 3]. Figure 2 presents a fitted graph of the relationship between EID and GT. This shows a U-shaped relationship between the two, which is consistent with H1. The results of the study show that EID has a negative impact on green transformation when EID of heavily polluting firms is less than 3 points. When the environmental information disclosure of heavy polluters is more than 3 points, EID has a positive effect on GT.

Columns (2), (4), (6), (8), and (10) of Table 6 show the regression results after adding the moderating variable MC, as in the five models above. The coefficient of EID^2*MC in column (2) is -0.499, which is significant at the 10% level. The coefficients of EID^2*MC in columns (4), (6), (8), and (10) are $-0.561, -0.570, -0.515$, and -0.523, respectively, which all pass the 5% significance test. The inflection point shift formula is constructed based on the correlation coefficients of formula model (3) and column (10)

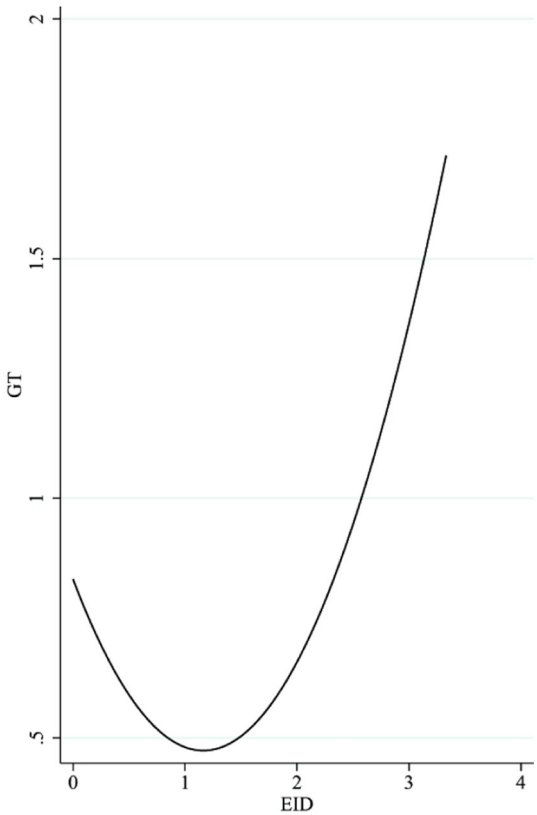

Fig. 2 Baseline regression U-plot

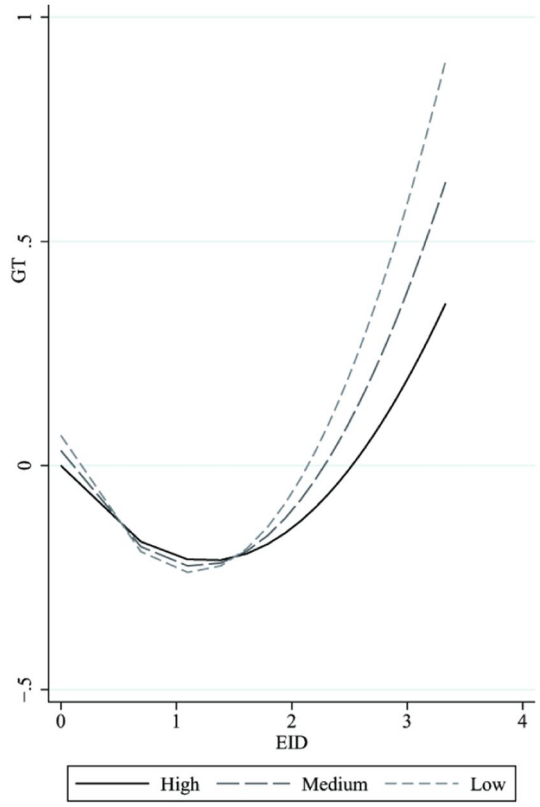

Fig. 3 U-shaped adjustment effect diagram

of Table 6: $\theta = (\alpha_1 * \alpha_6) - (\alpha_2 * \alpha_5)$ (Haans et al., 2016), which yields that θ is greater than 0. Market competition shifts the inflection point of the U-shaped curve to the right. The inflection point is calculated as 1.546 by column (10), and the environmental information disclosure score is (3, 4]. Figure 3 plots the moderating effect of MC where medium, high, and low levels are set as MEAN, MEAN+SD, and MEAN-SD, respectively. The results show that the U-shaped curve of EID and GT becomes smoother, and the inflection point shifts to the right as market competition becomes more intense. Hence, H2 is verified. The results of the study show that fierce market competition is not conducive to GT of heavily polluting companies. After adding the moderating variable of MC, the U-shaped curve of EID and GT is gradually smoothed, and the inflection point is increased from 3 to 4. When the demand for environmental information disclosure is greater than 4 points, EID has a positive effect on GT.

In summary, this study makes the following recommendations:

For heavily polluting companies, the greater the EID, the more beneficial is the green transformation of the enterprise. Companies should initiate the establishment of comprehensive environmental information management systems. A system linking managerial remuneration and job competency assessments to environmental performance can also be established. Market competition increases information risk. Therefore, companies simultaneously develop their own competitive advantages at the same time. They

must also balance the risks and opportunities brought about by environmental information disclosure, green transformations, and industry competition. Big data and high-tech technology should be actively introduced to reduce the cost of information disclosure and improve its efficiency of information disclosure.

Therefore, government should establish a sound system of EID. The government should standardize the content and standards of mandatory EID by heavily polluting companies. We should establish a regulatory system for EID, improve relevant laws and regulations, and incentivize companies to take the initiative to disclose environmental information. The government should regulate the market to prevent malicious competition and create a favorable competitive environment. It also should adhere to the principles of the rule of law and marketization to ensure the stability and security of EID and reduce the risk of transformation. Government should also adjust its industrial structure to respond differently to industries with different levels of competition.

5.4 Robustness tests

In this study, replacement of explanatory variables, lagged one period, and PSM test are taken as robustness tests. First, this study adjusted the scoring system of the original explanatory variables by referring to other scholars' research methods (Xi et al., 2022). Only two modules of environmental performance, governance and environmental liabilities, were selected for scoring: 0 points for no description, 1 point for qualitative description, and 2 points for quantitative description. Data processing methods remained unchanged. Second, to address the possibility of endogeneity in the explanatory, moderating, and control variables, the study regresses them all lagged by one period. Finally, propensity score matching (PSM) was done to correct for the endogeneity problem of possible selective bias. The sample is divided into treatment (high EID) and control (low EID) groups using the median environmental information disclosure as the boundary. All control variables were selected as covariates to construct Logit models, and nearest-neighbor matching was performed according to the 1:1 principle, resulting in 4097 sample values. The absolute values of standardized deviations (%bias) of the variables after matching are less than 10%, and the average treatment effect (ATT) of EID is significant at the 1% level. The results showed that the matching well balanced the data between the treatment group and the control group, meeting the balance trend test. According to Tables 7, 8, and 9, the results are consistent with the previous ones; that is, there is no substantial change in the significance of the main variables in the model. The test results indicate that the analysis results of this study are more stable and reliable.

6 Discussion

This study selects heavily polluting companies from 2011 to 2020 as sample to test the impact of EID on GT and the moderating role of MC. Scholars have already studied the relationship between EID and GT. They found that EID is positively correlated with green innovation (Ding et al., 2022; Wu et al., 2023). Unlike the existing literature, this study finds that there is a positive U-shaped relationship between EID and GT, with the inflection point of EID taking the value (2,3). When EID is lower than 3 points, it is negatively related to GT; when EID exceeds 3 points, it is positively related to GT. Based on transaction cost theory, signaling theory, and market pressure hypothesis, this study explores

Table 7 Robustness tests—Replacement of explanatory variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variables	GT	GT	GT	GT	GT	GT	GT	GT	GT	GT
s_EID	−0.425***	−0.267**	−0.358***	−0.224**	−0.328***	−0.191*	−0.376***	−0.267**	−0.347***	−0.232**
	(0.0815)	(0.117)	(0.0777)	(0.112)	(0.0771)	(0.111)	(0.0761)	(0.109)	(0.0755)	(0.109)
s_EID^2	0.214***	0.136***	0.165***	0.102***	0.159***	0.0924***	0.156***	0.0998***	0.150***	0.0897***
	(0.0230)	(0.0330)	(0.0220)	(0.0316)	(0.0218)	(0.0314)	(0.0215)	(0.0309)	(0.0213)	(0.0307)
MC		−0.724		−0.485		−0.141		−0.0769		0.265
		(0.708)		(0.678)		(0.675)		(0.662)		(0.659)
s_EID*MC		0.949		0.968		1.098		0.742		0.878
		(0.920)		(0.882)		(0.875)		(0.860)		(0.854)
s_EID^2*MC		−0.600**		−0.539**		−0.607**		−0.483**		−0.549**
		(0.256)		(0.245)		(0.244)		(0.239)		(0.238)
Control	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	No	No	No	No	Yes	Yes	No	No	Yes	Yes
Year	No	No	No	No	No	No	Yes	Yes	Yes	Yes
Constant	0.758***	0.651***	−0.208**	−0.210**	0.100	−0.0271	−0.687***	−0.651***	−0.381***	−0.435***
	(0.0620)	(0.0885)	(0.0864)	(0.105)	(0.0997)	(0.120)	(0.0932)	(0.110)	(0.105)	(0.123)
Observations	8,028	8,028	8,028	8,028	8,028	8,028	8,028	8,028	8,028	8,028
R-squared	0.064	0.087	0.155	0.166	0.174	0.181	0.199	0.207	0.214	0.221

***p-value < 1%; ** < 5%; and * < 10%; s_EID is the explanatory variable for replacement; *GT* Green transformation; *MC* Market competition; *s_EID^2* The 2nd power of s_EID; s_EID*MC: s_EID multiplied by MC; s_EID^2*MC: The 2nd power of s_EID multiplied by MC; Control: all control variables; Industry: fixed industry; and Year: fixed year

Table 8 Robustness tests—One-period lag

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variables	GT	GT	GT	GT	GT	GT	GT	GT	GT	GT
L.EID	−0.574***	−0.389**	−0.463***	−0.276*	−0.473***	−0.315**	−0.538***	−0.385***	−0.547***	−0.419***
	(0.109)	(0.158)	(0.105)	(0.152)	(0.104)	(0.151)	(0.103)	(0.148)	(0.102)	(0.147)
L.EID^2	0.250***	0.171***	0.187***	0.116***	0.192***	0.125***	0.198***	0.137***	0.203***	0.145***
	(0.0281)	(0.0405)	(0.0270)	(0.0391)	(0.0269)	(0.0389)	(0.0263)	(0.0380)	(0.0262)	(0.0379)
L.MC		−0.710		−0.867		−0.168		−0.356		0.270
		(1.152)		(1.108)		(1.101)		(1.076)		(1.070)
L.EID*L.MC		0.882		1.277		1.099		0.946		0.781
		(1.251)		(1.202)		(1.191)		(1.167)		(1.156)
L.EID^2*L.MC		−0.520*		−0.565*		−0.572*		−0.480*		−0.481*
		(0.312)		(0.299)		(0.297)		(0.291)		(0.288)
L.Control	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	No	No	No	No	Yes	Yes	No	No	Yes	Yes
Year	No	No	No	No	No	No	Yes	Yes	Yes	Yes
Constant	0.878***	0.741***	−0.0531	−0.109	0.269**	0.0828	−0.511***	−0.518***	−0.200	−0.306*
	(0.0965)	(0.140)	(0.122)	(0.156)	(0.133)	(0.168)	(0.123)	(0.156)	(0.135)	(0.167)
Observations	6,670	6,670	6,670	6,670	6,670	6,670	6,670	6,670	6,670	6,670
R-squared	0.070	0.091	0.156	0.167	0.176	0.183	0.209	0.216	0.225	0.231

***p-value < 1%; ** < 5%, and * < 10%; *L* One-period lag; *L.EID* Environmental information disclosure with a one-period lag; *GT* Green transformation; *L.MC* Market competition with a one-period lag; *L.EID^2* The 2nd power of L.EID; *L.EID*L.MC* L.EID multiplied by L.MC; *L.EID^2*L.MC* The 2nd power of L.EID multiplied by L.MC; *L.Control* All control variables with a one-period lag; Industry: fixed industry; and Year: fixed year

Table 9 Robustness test—PSM

	(1)	(2)	(3)	(4)	(5)
Variables	GT	GT	GT	GT	GT
EID	−0.475***	−0.356***	−0.330**	−0.479***	−0.441***
	(0.138)	(0.132)	(0.132)	(0.130)	(0.130)
EID^2	0.207***	0.167***	0.160***	0.183***	0.172***
	(0.0354)	(0.0339)	(0.0339)	(0.0332)	(0.0332)
Control	No	Yes	Yes	Yes	Yes
Industry	No	No	Yes	No	Yes
Year	No	No	No	Yes	Yes
Constant	0.776***	−0.407**	−0.107	−0.812***	−0.528***
	(0.124)	(0.167)	(0.182)	(0.168)	(0.183)
Observations	4097	4097	4097	4097	4097
R-squared	0.052	0.139	0.152	0.188	0.200

***p-value < 1%; ** < 5%; and * < 10%; *EID* Environmental information disclosure; *GT* Green transformation; *EID^2* The 2nd power of EID; Control: all control variables; Industry: fixed industry; and Year: fixed year

the mechanism of EID on GT, which is mainly due to the cost, resource, and monitoring effect. The findings of this study provide a new researchable perspective on the relationship between EID and GT. Market competition flattens the U-shaped relationship between the two, and the inflection point for EID becomes (3, 4). Research on market competition on disclosure and innovation has been of academic interest. This study explores the impact of market competition on EID and GT based on the theory of cost competitive advantage and Schumpeter hypothesis, respectively, to provide theoretical support for the final results. The purpose of promoting the green transformation of heavily polluting companies is mainly to realize the benign interaction between sustainable economic development and environmental protection (Li et al., 2023; Zhai & An, 2020), and GT of manufacturing affects the greening of the economy (Chen et al., 2023). This study explores a feasible path for the GT of heavily polluting companies, which has a positive impact on companies, society, and the environment.

7 Conclusions

7.1 Theoretical implications

First, this study explains the impact mechanism of EID on GT from several perspectives, including transaction cost theory, signal theory, and market pressure hypothesis, and is supported by empirical tests. It provides a theoretical basis for companies to take the initiative to protect the environment and fulfill their disclosure responsibilities. Unlike the previous literature that concluded that there is a linear relationship between the two (Wang & Shao, 2023), this study concludes that there is a nonlinear U-shaped relationship between EID and GT. This provides new literature and perspectives on the nonlinear relationship between EID and GT.

Finally, there has been a large body of the literature empirically testing the external governance function of market competition for firms. This study uses the cost competitive advantage theory and Schumpeter hypothesis to explain the regulatory role played by market competition and empirically test it. It provides a theoretical basis for heavy polluting companies to formulate competitive strategies and for the government to dynamically regulate the market. The findings of the study also enrich the literature on the negative impact of market competition on markets.

7.2 Managerial contributions

First, the EID is one of the most important ways to gain a differentiated competitive advantage. Although environmental information is still a non-mandatory disclosure item for most companies, it is for this reason that companies can gain a differentiated competitive advantage through voluntary disclosure of environmental information. And when EID exceeds a certain amount, it has a facilitating effect on the GT of companies. This finding can stimulate managers' intrinsic motivation to voluntarily disclose environmental information.

Finally, fierce market competition is not conducive for companies to improve EID and GT. Since EID and green innovation are both high-risk large-scale capital projects, fierce market competition will make the management more cautious about the allocation of corporate funds and give up high-risk projects to ensure corporate profits (Habib & Mourad, 2022). However, international green development has become an inevitable trend. In order not to be eliminated from the market, companies first need to improve their environmental information disclosure technology and efficiency to take advantage of the competition.

7.3 Limitations and future research perspectives

First, there are two general types of indicators for measuring green transformation, one being green innovation indicators and the other being green total factor productivity indicators. Green total factor productivity is usually modeled using the unintended slacks-based measure (SBM) model, which requires consideration of unintended output. However, there is a serious lack of data on the environmental unintended output of firms, so green total factor productivity is mostly used in macroeconomic studies. Therefore, after the data on firms' environmental non-desired outputs are enriched, future studies can use green total factor productivity to measure firms' green transformation. Second, regarding the scoring indicators for environmental information disclosure, this study selects all non-financial information. In the future studies, consider incorporating financial metrics, running DEA, or factor analysis to measure. Finally, the sample of this study, while a feature of the article, has some limitations. The results of this study are only for heavy polluters. It is also worth exploring the green transformation pathways of other industries in China.

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Data availability The data that support the findings of this study are openly available Science Data Bank at https://www.scidb.cn/s/BfIjUb.

Code availability The code of the model is available from the authors upon reasonable request.

Declarations

Competing interests The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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