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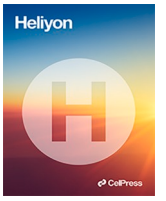

Research article

How does market-incentive environmental regulation affect enterprises green growth? The mediating role of R&D investment and innovation output

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ABSTRACT

Manufacturing enterprises is a country's economic mainstay. However, their longtime extensive growth pattern of "high growth and high emission" has brought huge environment pollution and restricted sustainable development. Under the circumstance of carbon reduction and global green development, market-incentive environmental regulation (MER) has attracted the attention of scholars and become a kind of important methods of encouraging manufacturing enterprises green growth. Presently, two fairly distinct viewpoints of "Follow Cost" and "Porter Hypothesis" both have their own supportive research results, and the explanation for the role of MER is completely opposite. What's more, empirical research at the enterprise level is scarce. Therefore, this study makes a further analysis from the perspective of enterprises heterogeneous innovation ability. Guided by the classic theory of "Follow Cost" and "Porter Hypothesis", this study aims to evaluate the applicable conditions of MER's environmental improvement effect, and testing the differential impact mechanism of MER on enterprise Green Total Factor Productivity (GTFP), enterprise Green Technological Change (GTC) and enterprise Green Efficiency Change (GEC). All these give theoretical and empirical supplementation for the rationality of related theories. This study examines the hypotheses and mechanism according to 1220 Chinese manufacturing listed companies data 2011–2020. The empirical results indicate that: (1) In short term, MER has a significant positive impact on GTC, and a significant negative impact on GTFP and GEC. (2) As innovation driven factors, both enterprise R&D investment and innovation output play the mediating role. (3) Heterogeneity analysis indicates that the impact mechanism varies depending on enterprise industry-type, location and digital level. Thus, policymakers should develop appropriate MER policies, and manufacturing enterprises should strengthen technological innovation to help achieve environmental sustainability and profit performance.

1. Introduction

Since China implemented the "Reform and Opening-up Policy", it's economy has grown rapidly and made remarkable achievements. However, their longtime extensive growth pattern of "high growth and high emission" has brought huge environment pollution and limited economy's sustainable development. Data from "The 2022 Environmental Performance Index Report" showed that China

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ranks 160th in the overall environmental performance index among 180 countries worldwide, indicates that Chinese economy is facing the pressure from ecological issues. At the same time, the world economy is showing a green and low-carbon trend. Under this background, sustainability has become a crucial concern. Chinese government and enterprises have fully realized the importance of green and sustainable development. China's 2035 Long-range Goals have clearly emphasized that China will pursue the clean and efficient use of energy, and promote comprehensive green development. Seeking a balance between environmental performance and economic performance has become an urgent problem to be solved not only for China but also for the whole world's economic development [1]. Manufacturing enterprises are not only an important component of the national economy, but also a major source of carbon emissions. Manufacturing enterprises often catch up in a dilemma between environmental pollution and profit growth during their development process. Therefore, studying manufacturing enterprises sustainable development has become crucial than ever [2].

The importance of ER on green growth has gradually attracted the attention of scholars [3,4]. The ER may force corporate behavior in the form of commands, may guide corporate direction through incentive measures, and may even regulate corporate social responsibility through supervision. The root-source of environmental pollution is the externality of economic behavior, and MER is an effective means to solve the externality of economic activities. MER aim to guide enterprises to internalize external environmental costs through economic means, thereby achieving green production. As one of the most effective regulation means, most countries around the world choose to use MER to solve environmental problems [5,6]. However, related researches mainly carries on the discussion from the macro level of the urban and industry [7], and the researches on enterprise level is still scarce.

Under the circumstance of carbon reduction and global green development, MER has become an important method of encouraging enterprises green growth. However, their explanation for the role of MER is completely opposite, and there exists "the Green Paradox". The "Follow Cost" theory given that strict environmental regulation often increase enterprises environmental protection burden, then restrain enterprises production efficiency and profitability, and furthermore decrease GTFP [7,8]. But "Porter Hypothesis" theory proposes that appropriate environmental regulation can enhance resource allocation level, improve production processes, increase production efficiency, stimulate technological innovation, and ultimately achieve Pareto improvement, and these can offset the environment investment costs [9]. Subsequent researchers further divided the "Porter hypothesis" into two sub-kinds of weak and strong [10]. The "Weak Porter Hypothesis" proposes that ER can enhance GTFP by stimulating technological innovation [11]. The "Strong Porter hypothesis" proposes that ER can improve production efficiency, and the remarkable efficiency increasing are sufficient to offset regulatory costs, resulting in an "Innovation Compensation Effect" and thus enhancing green total factor productivity [12,13].

Some researchers have given that the "Follow Cost" theory is effective for a short period and the "Porter hypothesis" theory is effective for a long period. However, more researchers believe that time factors are not the decisive factor. Berman and Bui conducted a study on some refineries on the South Coast of Los Angeles in the U.S., and found that although the strict environmental regulations caused cost increasing, but they finally improved green total factor productivity [14]. Boyd also found that technological advancement brought by environmental regulations promotes productivity and environmental performance of glass industry, and the "Innovation Compensation Effect" can exceed the efficiency loss caused by environmental regulations [15]. He's study found that more heavily regulations on enterprises will lead to productivity loss, which was mainly result in more investing in abatement equipment to meet tighter regulations, and this cause a decrease in enterprise productivity [16]. Leeuwen pointed out that the contribution of any type of eco investment to technological product and process innovation is relatively small, and ER will restrain technological innovation and reduce manufacturing productivity [17].

The above empirical research results indicate that the impact of ER on enterprises green growth is complex, there may exists positive, negative, nonlinear, or even no correlation between them. Therefore, it is necessary to explore a new perspective to give a reasonable explanation on the paradox. The possible causes are as following. Firstly, enterprises GTFP can be further divided into two sub-dimensions which are enterprise green technology change (GTC) and enterprise green efficiency change (GEC), mixing these varies indicators lead to inconsistent research conclusions [18]. Therefore, the differentiated impact of MER on different sub-dimensions of enterprise green growth has become a new direction. Secondly, the essence of MER' green effect is to promote enterprise to internalize the outer cost on eco-environment protection into the inner cost. Different extent of enterprise innovation capability can further stimulate different degree of "Innovation Compensation Effect". Thus, it is essential to explore heterogeneous enterprise's MER environmental impact effect, by considering key factors affecting enterprise innovation capability. Thirdly, related researches mainly focuses on macro level and related researches on enterprise level is insufficient [7]. Therefore, research at the micro enterprise level is essential.

The lacks of existing researches provide new possibilities for this study. Therefore, this study makes a further analysis from the perspective of enterprises heterogeneous innovation ability. The main research objectives of this article include giving a more reasonable explanation on classic theories of "Follow Cost" and "Porter Hypothesis", and testing its differential impact mechanism on GTFP, GTC and GEC. All these will be meaningful supplementations for related theories.

The empirical research is based on 1220 Chinese manufacturing listed enterprises panel data 2011–2020. According to the empirical results: (1) MER has a direct positive impact on GTC, while a direct negative impact on GTFP and GEC. (2) As innovation driven factors, both enterprise R&D and IO play the mediating role. (3) Heterogeneity analysis indicates that the impact mechanism varies depending on the industry type of enterprise, enterprise location and digital level. Thus, policymakers should develop appropriate MER policies, and manufacturing enterprises should concern technological innovation to help achieve environmental sustainability and profit performance.

The main contributions are as following: (1) Focusing on the micro level of and using enterprises data, we further divide enterprises GTFP into two sub-dimensions including GTC and GEC, then analyzes the impact of MER on different indicators, and expands the explanatory scope of existing classic theories; (2) From the perspective of innovation driven capacity, this paper introduces enterprise R&D and IO as mediating variables, clarifies the mechanism of MER affect enterprises green growth and the role of enterprises

heterogeneous innovation capability, explores the conditions for "Innovation Compensation Effect" and "R&D Crowding Out Effect", which is a supplementation to relevant theoretical systems; (3) This paper conducts the heterogeneity discussion according to the industry type of enterprise, enterprises location and enterprises digital level. The results may not only help to explicit the different impacts of various influencing factors but also provides a decision-making basis for formulating MER policies to promote enterprises green growth.

2. Literature review

2.1. MER and enterprises green growth

In recent years, eco-friendly has become a popular concept, and green growth represents the general trend [19]. The role of ER on green growth shows increasing importance [20]. The divergence of its distinct effect has inspired scholars to think about the differentiated impact of its subcategory. According to related researches, ER can be further divided into three sub-categories of command-control, market-incentive and public-participation [18]. Economic means are the main measures to regulate economic activities, and the incentive role of MER is most crucial. Thus, MER's impact on enterprises green growth will be mainly discussed.

MER can strengthen institutional support for enterprises green growth by implementing economic policies such as pollution emission fines, investment of environmental pollution control, tradable pollution permits, energy-saving and emission reduction subsidies [21,22]. The empirical research of Feng and Chen verified MER's incentive role to new-energy companies green innovation [23]. However, the results from Gray and Shadbegian showed that MER will have a negative influence on GTFP [24].

According to the classic theory of "Follow Cost", MER will lead to enterprises cost increasing due to pollution control, and inhibit its GTFP. However, the theory of "Porter hypothesis" given that in the long run, MER can stimulate enterprises innovation practice and technological progress, and improve its GTFP. We mainly try to explore the impact of MER on enterprise' short-term green growth in this article. Thus, based on the theory of "Follow Cost", it is believed that MER inhibit enterprises green growth.

All the above analysis indicates that relevant research still needs to be deepened especially from the micro enterprise level. Moreover, the existing analysis focused on the micro enterprise level is still insufficient. In addition, GTFP includes two sub-dimensions of GEC and GEC, and discussions neglecting different sub-dimensions may be the reason for inconsistent research conclusions. Therefore, it is necessary to further subdivide enterprises GTFP.

Thus, Hypothesis 1 and its sub-hypotheses are proposed.

Hypothesis 1. MER can improve enterprises green growth.

Hypothesis 1a. MER can improve enterprises GTFP.

Hypothesis 1b. MER can improve enterprises GTC.

Hypothesis 1c. MER can improve enterprises GEC.

2.2. The mediating role of enterprises R&D investment

Under the background of high-quality development, creating new development advantages by innovation driven has become the route enterprises must take [25]. Increasing R&D investment by enterprises is the key measure to achieve pollution control [26,27].

Some researches gave the view that the stricter MER is, the stronger its governance effect is, and the more it can push enterprises green developing by increasing R&D investment. ER is a mean rather than the aim, and the ultimate goal is to achieve green growth. MER can stimulate increased technological investment, thereby promoting enterprises green growth. MER tools represented by transaction permissions show obviously promoting effect on R&D investment and environmentally friendly technology diffusion [11]. However, some studies also suggest that current environmental regulations have no significant impact or even short-term negative impact on enterprises R&D investment [28,29].

R&D's promoting effect on economic green development has been confirmed by most scholars. MER is the most effective environmental regulation, which will incentive enterprise' R&D investment, thereby promoting its green innovation [22,23]. Based on the high-tech enterprise data in China 2012–2017, researchers confirms that environmental regulations significantly improve R&D investment, and innovation investment plays the mediating role [30].

According to the "Follow Cost" theory, in short term, constrained by the total amount of capital, MER will increase enterprises pollution control costs and decrease enterprises R&D investment simultaneous, which known as the "R&D Crowding Out Effect" [31]. Therefore, the impact of MER on GTFP is negatively significant [24]. According to the "Porter Hypothesis" theory, in the long run, innovative practices and efficiency improvements triggered by ER can offset the cost of environmental investment, generate an "Innovation Compensation Effect", and improve GTFP [32]. Both of the above effects are reasonable to a certain extent. The disagreement lies in the mechanisms and extent of MER's innovation driving effect.

Enterprise R&D investment may be a cost in short term and potential innovation capability in the future. Its heterogeneity can affect the degree of environmental regulations "Innovation Compensation Effect". Thus, this article focuses on the internal innovation driving factors of enterprises, analyze the mechanisms and extent of MER's innovation driving effect, and further analyzes the mediating role of enterprise R&D investment.

Thus, Hypothesis 2 and its sub-hypotheses are proposed.

Hypothesis 2. R&D investment plays the mediating role in the process of MER affect green growth.

Hypothesis 2a. R&D investment plays the mediating role in the process of MER affect GTFP.

Hypothesis 2b. R&D investment plays the mediating role in the process of MER affect GTC.

Hypothesis 2c. R&D investment plays the mediating role in the process of MER affect GEC.

2.3. The mediating role of enterprises innovation output

MER will affect enterprise innovation output, and ultimately affect enterprises GTFP through innovation driving effects [6]. "Porter Hypothesis" indicates that ER can significantly increase competitiveness through incentivizing innovation [33,34]. Environmental regulation affects enterprises green growth by stimulating their innovation vitality [35,36]. The "Follow Cost" theory given that the strict ER will increase the environmental governance costs, resulting in "R&D Crowding Out Effect" that is negative to innovation output [24].

Using 78 enterprises data from 2012 to 2020, the research results show that ER has a substantial impact in promoting green technological innovation [23]. Using Chinese A-shared high-tech enterprises 2012–2017 as samples, the results find MER help guide the manufacturing industry to accelerate technology innovation and achieve green growth [30]. Endogenous and directional technological changes under the growth model of environmental constraints can lead to enterprises increasing production costs, thereby hindering their technological innovation to a certain extent [37]. Gollop and Robert's study using data from U.S. electric power enterprises found that under strict environmental regulatory policies, enterprises have to use more low sulfur coal to reduce SO_2 emissions, which is detrimental to enterprises production efficiency and innovative output [38]. Barbers and McConnell proposed that strict ER can decrease enterprises innovation, especially in the short run, more pollution control investment will result in low innovation output and enterprise performance [39].

Enterprise innovation ability can affect enterprise green growth [40–42]. The more innovative output an enterprise produces, the easier it is to achieve green growth. There are differences in the driving effects at the enterprise level due to enterprises heterogeneity, and the extent of innovation driving effect can be measured by innovation output [43]. The driving role of innovation in economic development has been supported by numerous studies. However, it remains unclearly of whether and how MER affecting enterprises innovation output. Then, clarifying the mediate role of innovation output is necessary.

Different enterprises have different innovation capabilities. The extent of ER influence is determined by the compensation extent of environmental regulatory costs. Either the "R&D Crowding Out Effect" or the "Innovation Compensation Effect" are eventually determined by the enterprises innovation ability. Therefore, firstly, MER has a direct impact on enterprises green growth. Secondly, enterprises heterogeneity measured by their innovation output can affect the impact degree of MER, that is, enterprises innovation output may strengthen or weaken MER's impact on enterprises green growth. Thus, this article further analyzes the mediating role of enterprise innovation output.

Thus, Hypothesis 3 and its sub-hypotheses are proposed.

Hypothesis 3. Innovation output plays the mediating role in the process of MER affect green growth.

Hypothesis 3a. Innovation output plays the mediating role in the process of MER affect GTFP.

Hypothesis 3b. Innovation output plays the mediating role in the process of MER affect GTC.

Hypothesis 3c. Innovation output plays the mediating role in the process of MER affect GEC.

3. Research methodology

3.1. Sample selection

Based on the analysis above, research on Chinese manufacturing listed companies as samples is typical and necessary. In view of this, in order to fulfill the purpose of this study, 1220 A-share manufacturing enterprises data are collected from China Stock Market and Accounting Research Database (CSMAR) by the following method: (1) A-share manufacturing enterprises involving 31 industries were selected according to the industry classification codes 2012 Revision; (2) Sample enterprises been warned by ST and *ST are excluded; (3) Sample enterprises with lots of missing data are excluded.

ST represents "Special Treatment", which means the sample company has made a loss for two consecutive accounting years after auditing, and there is a significant operational risk. *ST represents "Special Treatment" in deep degree, means the listed company has made a loss for three consecutive accounting years after auditing, and will be warned delisting. Remove samples with ST and *ST for the following reasons: (1) Enterprises that have been ST and *ST indicates significant abnormal fluctuations in its financial indicators, and this is disturbance terms that affect the stability of regression results; (2) Listed companies awaiting be delisted don't disclose the annual reports, and relevant data cannot be obtained; (3) The number of ST and *ST sample enterprises involved in the paper is extremely small. Taking into account the above factors and drawing on relevant researches' methods, these samples are excluded.

In order to eliminate the unstable possible impacts of the Coronavirus pandemic and draw relatively stable and reliable conclusions, the research period in this paper is from 2010 to 2020. Finanlly, 12200 pieces of data are collected.

3.2. Variable description and data sources

3.2.1. Dependent variables

The dependent variable is enterprises green growth, which is measured by enterprises GTFP, enterprises GTC and enterprises GEC. Enterprises are the micro entities of economic activities. Under sustainable development background, the measurement of enterprises green growth has attracted much attention. Super-SBM Model is used in this article, both desirable and undesirable outputs are included in the optimal frontier model for enterprises green growth [44,45], then we calculate enterprises GTFP and further divide it into two sub-dimensions: enterprises GTC and enterprises GEC [46,47].

There are standard formulas for calculating GTFP, GTC, and GEC, and there is no algorithmic innovation in this article. Besides, this calculation process can automatically do by MATLAB software, so this article does not present the calculation process and only introduces the necessary data for calculation.

To calculate the dependent variables, all the related factors including input factors, desirable and undesirable output are considered. Based on literatures [48,49], capital, labor, intermediate and energy input can all be seen as input factors. The output factors include both desirable and undesirable factors. The desirable output refers to "enterprises main business income". The undesirable output refers to "enterprise main industrial wastes". Referring to the general method, the undesirable output can be further divided into three sub-types. The relevant data sources and detailed calculation methods are shown in Table 1. In view of the limited research data, the three kinds of industrial wastes are at the city level, and then transformed into enterprise level. More specifically, the percentage of total enterprise output to total industrial output is calculated year-by-year, and then the three kinds of industrial wastes can be transformed into enterprise level according to the proportion. Relevant data are gained from CSMAR, China Statistical Yearbook (CSY), China City Statistical Yearbook (CCSY) and China Environmental Statistical Yearbook (CESY).

3.2.2. Independent variable

The independent variable is MER. MER is a kind of market-oriented environmental regulations, which can strengthen institutional support for enterprises green growth by implementing economic policies such as pollution emission fines, investment of environmental pollution control, tradable pollution permits, energy-saving and emission reduction subsidies [50,51]. Although pollution emission fines are relatively common, further in-depth discussion is not possible constrained by the lack of enterprise level data. Tradable pollution permissions and related subsidies have insufficient overall application and lack nationwide data [52,53]. While the

Table 1
Calculation indicators for enterprises' GTFP, GTC and GEC.

	Type (Data sources)	Variable	Calculation method
Input factors	Non energy (CSMAR)	Capital	$C_t = C_{t-1}(1-\delta_t) + I_t/P_t$ Fixed assets' net value. C_t: the stock of capital in period t, C_{t-1}: the stock of capital in period t-1. δ_t represents depreciation rate, and it equals to 5 % in this paper (Cui and Lin, 2019). I_t is enterprise fixed asset investment in period t. P_t is the price indices for investment in fixed assets of the region where enterprise registration place is.
		Labor	Employees salary and other cash paid by enterprise.
		Intermediate	$N_t = (O_t + S_t + F_t + M_t) - (C_t + D_t)$ Necessary inputs minus necessary expenses. N_t: intermediate input in period t. O_t: operating costs in period t. S_t: sales expenses in period t. F_t: financial expenses in period t. M_t: management expenses in period t. C_t: cash paid to employees in period t. D_t: depreciation and amortization in period t.
	Energy (CSMAR, CESY)	Energy	$EI_{e,t} = EI_{i,t} \times OV_{e,t}/OV_{i,t}$ $EI_{e,t}$: enterprise energy input in period t. $EI_{i,t}$: the whole industry's energy input in period t. $OV_{e,t}$: enterprise gross output value in period t. $OV_{i,t}$: the whole industry's gross output value in period t.
Output factors	Desirable (CSMAR)	Income	Enterprises main business income.
	Undesirable (CSMAR, CSY, CCSY)	Wastewater	$W_{e,t} = W_{c,t} \times OV_{e,t}/OV_{c,t}$ $W_{e,t}$: enterprise industrial wastewater output in period t. $W_{c,t}$: the whole city's industrial wastewater output in period t. $OV_{e,t}$: enterprise gross output value in period t. $OV_{c,t}$: the whole gross output value of city's above-scale industrial enterprise in period t.
		SO_2	$SO_{2,e,t} = SO_{2,c,t} \times OV_{e,t}/OV_{c,t}$ $SO_{2,e,t}$: enterprise SO_2 output in period t. $SO_{2,c,t}$: the whole city's SO_2 output in period t. $OV_{e,t}$: enterprise gross output value in period t. $OV_{c,t}$: the whole gross output value of city's above-scale industrial enterprise in period t.
		Emissions	$E_{e,t} = E_{c,t} \times OV_{e,t}/OV_{c,t}$ $E_{e,t}$: enterprise industrial-smoke emissions output in period t. $E_{c,t}$: the whole city's industrial-smoke emissions output in period t. $OV_{e,t}$: enterprise gross output value in period t. $OV_{c,t}$: the whole gross output value of city's above-scale industrial enterprise in period t.

continuous annual data of regional environmental pollution investment can be obtained from related annual report [22]. Considering these reasons, this article uses it to measure MER. To eliminating the interference of regional gross economic scale, the investment in environmental pollution control in this article is calculated by proportional indicators. Specifically, it is equal to the investment in preventing and controlling industrial pollution in each region divided by the regional GDP [53]. Relevant data are collected from CSMAR and CESY.

3.2.3. Mediating variables

The mediating variables are enterprises innovation driven factors, including R&D investment (RD) and innovation output (IO). R&D equals enterprise R&D amount divided by its sales revenue, and IO means enterprise awarded patents amount. Relevant data are gained from CSMAR and China National Intellectual Property Administration (CNIPA).

3.2.4. Control variables

Referring to related theories and researches, the following variables are chosen as control variables in this paper: return on assets (ROA), asset liability ratio (ROL), total asset turnover (TAT) and enterprise scale (Scale). ROA is enterprises net profit divided by its total assets. ROL is enterprises total liabilities divided by its total assets. TAT is enterprise total sales revenue divided by its total assets. Scale is represented by its total assets. Relevant data are all from CSMAR.

Variables summary is shown in Table 2.

3.3. Model construction

On the research of MER on enterprises green growth, there exists two different views of "driving role" and "hindering role" [10]. This study proposes that MER can affect enterprises, while due to individual differences, the cost increase and innovation compensation are quite different, which may further lead to enterprises' heterogeneous responses to the same MER. Therefore, introducing enterprise innovation driving factors as mediating variables and making further analysis will be helpful to elucidate the influence mechanism. In view of this, we choose to make the mediating effect analysis in this article. Thus, the related models are constructed.

3.3.1. Benchmark regression model

According to the above analysis, we will further test for the direct impact of MER on enterprises green growth, and it is necessary to construct a basic linear regression equation. The Hausman test results indicate that it is should use a fixed effects model. Therefore, this paper preliminarily constructs the benchmark regression model show as Eq. (1).

$$LnY_{i,t} = \varphi_0 + \beta_1 LnMER_{i,t} + \rho_i Controls_{i,t} + \mu_i + \varepsilon_{i,t} \tag{1}$$

In the equation, $Y_{i,t}$ represents the dependent variable set of enterprise i in year t, including GTFP, GTC and GEC. $MER_{i,t}$ indicates MER faced by enterprise i in year t. RD_{it} and IO_{it} represent R&D investment and innovation output of enterprise i in year t. $Controls_{i,t}$ represents the control variables of sample enterprise i in year t. φ_0 is constant terms, β_1、ρ_i are the regression parameters, μ_i is the unobservable individual effect, $\varepsilon_{i,t}$ is the random error term.

3.3.2. Mediating effect model

To test for the mediating role of enterprise, the following mediating effect testing models are constructed [54], show as Eq. (2). to Eq. (7).

$$LnY_{i,t} = \varphi_0^{'} + \beta_2 LnRD_{i,t} + \rho_i Controls_{i,t} + \mu_i + \varepsilon_{i,t} \tag{2}$$

$$LnY_{i,t} = \varphi_0^{'} + \beta_2 LnIO_{i,t} + \rho_i Controls_{i,t} + \mu_i + \varepsilon_{i,t} \tag{3}$$

$$LnRD_{i,t} = \theta_0 + \beta_4 LnMER_{i,t} + \rho_i Controls_{i,t} + \mu_i + \varepsilon_{i,t} \tag{4}$$

Table 2
Variables summary.

Variable	Name	Measurement	Data sources
Dependent variables	GTFP	input, desirable output,	CSMAR, CSY, CCSY, CESY
	GTC	undesirable output;	
	GEC	Super-SBM Model,	
		Malmquist index	
Independent variable	MER	enterprise environmental pollution control investment	CSMAR, CESY
Mediating variables	RD	R&D/sales revenue	CSMAR
	IO	enterprise awarded patents amount	CNIPA
Control variables	ROA	enterprises net profit/total assets	CSMAR
	ROL	enterprises total liabilities/total assets	CSMAR
	TAT	enterprise total sales revenue/total assets	CSMAR
	Scale	enterprise total assets	CSMAR

$$LnIO_{i,t} = \theta_0^{'} + \beta_5 LnMER_{i,t} + \rho_i Controls_{i,t} + \mu_i + \varepsilon_{i,t} \quad (5)$$

$$LnY_{i,t} = \delta_0 + \beta_6 LnMER_{i,t} + \gamma_1 LnRD_{i,t} + \rho_i Controls_{i,t} + \mu_i + \varepsilon_{i,t} \quad (6)$$

$$LnY_{i,t} = \delta_0^{'} + \beta_7 LnMER_{i,t} + \gamma_2 LnIO_{i,t} + \rho_i Controls_{i,t} + \mu_i + \varepsilon_{i,t} \quad (7)$$

In these equations, $Y_{i,t}$ represents the dependent variable set of enterprise i in year t, including GTFP, GTC and GEC. $MER_{i,t}$ indicates MER faced by enterprise i in year t. RD_{it} and IO_{it} represent R&D investment and innovation output of enterprise i in year t. $Controls_{i,t}$ represents the control variables sample enterprise i in year t. $\varphi_0^{'}$、$\varphi_0^{''}$、θ_0、$\theta_0^{'}$、δ_0、$\delta_0^{'}$are constant terms, α_i、β_i、γ_i、ρ_i are the regression parameters.

4. Results and analysis

4.1. Baseline regression

The estimation results of Eq. (1) are shown in columns (1), (2), and (3) in Table 3. In column 1, GTFP is the explained variable of the first model. In column 2, GTC is the explained variable of the second model. In column 3, GEC is the explained variable of the third model. As shown in every models, MER is significantly related to every enterprise green growth indicators. More specifically, in the short term, the coefficients of MER's effect on GTFP and GEC are negative significant at the 1 % level respectively, indicates that MER increased enterprises ecological governance cost. The result verifies the theory of the "Follow Cost". Meanwhile, the coefficient of MER's effect on GTC is positive significant at the 1 % level, showing that MER also generates "Innovation Compensation Effect", and then result in high GTC. Thus the weak "Porter Hypothesis" is confirmed.

ROL has a significant negative impact on GTC at the 1 % level, which means a higher ROL is not conducive to enterprises technology progress. TAT's impact on GTFP and GTC are both significant negative at the 1 % level. The possible reasons lie in two sides. On the one hand, a higher TAT often leads to an increase in production and emissions, thus negatively affecting GTFP. On the other hand, a higher TAT more emphasis on the short-term production and is cautious in dealing with risky R&D activities, thus negatively impacting GTC. At the 1 % level, enterprise scale has a negative impact on GTFP and GEC, while has a positive impact on GTC simultaneously. The possible reason is that large-scale manufacturing enterprises often have more technology and experience accumulating, which is positive to green technology improvement. Meanwhile, large-scale manufacturing enterprises often suffer from low operational efficiency due to their large institutions, which is negative to the improvement of technical efficiency and enterprises overall GTFP.

Thus, Hypothesis 1a and Hypothesis 1c are both positive supported, while Hypothesis 1b is reverse supported. Overall, Hypothesis 1 received partial positive and partial negative support from empirical results.

The baseline regression results show that dividing sub-dimensions of GTFP helps to clarify the complex impact of MER on enterprises green growth. The "Follow Cost" and "Innovation Compensation" are valid under certain conditions, and the role of enterprises heterogeneous innovation driving capabilities is worth of exploring. Therefore, the paper will continue to discuss the intermediary mechanism MER's impact on enterprises green growth.

4.2. Mediating mechanisms

The estimation results of Eq. (2) and Eq. (3) are shown in Table 4. Enterprise R&D investment has a positive significant effect both on GTFP and on GTC, but has no significant effect on GEC. Enterprise innovation output has a positive significant effect both on GTFP and on GEC, but has no significant effect on GTC.

This indicates that enterprises R&D investment mainly promote the development of new technologies, while innovation output

Table 3
The effect of MER on enterprise green growth, baseline estimations.

Dependent variable	(1) LnGTFP	(2) LnGTC	(3) LnGEC	(4) LnRD	(5) LnIO
LnMER	−0.033*** (−2.99)	0.296*** (13.48)	−0.588*** (−16.65)	−0.312** (−2.03)	−0.294*** (−4.86)
LnROA	−0.000 (−0.23)	0.000 (1.38)	0.000 (−1.22)	−0.002 (−1.00)	0.000 (0.65)
LnROL	−0.000 (−0.72)	−0.000*** (−5.08)	0.000 (0.35)	−0.002*** (−2.78)	−0.000 (−0.76)
LnTAT	−0.071*** (−3.48)	−0.070*** (−3.39)	0.026 (0.70)	−1.316*** (−5.68)	−0.030 (−0.43)
LnScale	−0.059*** (−12.17)	0.109*** (17.30)	−0.384*** (−23.73)	−0.284*** (3.36)	0.521*** (14.52)
_cons	2.082*** (18.49)	−1.873*** (−12.70)	9.935*** (27.03)	−1.085 (−0.57)	−9.321*** (−11.52)
Sigma_u	0.083	0.151	0.454	3.253	1.490
Sigma_e	0.185	0.499	0.796	2.347	0.949
rho	0.169	0.084	0.245	0.693	0.711
R^2	0.029	0.023	0.068	0.025	0.086
F	37.52***	86.13***	147.04***	15.17***	52.98***

Note: ***, ** and * indicate the statistical significance of 1 %, 5 % and 10 % respectively. The characters in other tables of this paper have the same interpretation.

Table 4
The mediating effect of RD and IO.

Dependent variable	(1) LnGTFP	(2) LnGTC	(3) LnGEC	(4) LnGTFP	(5) LnGTC	(6) LnGEC
LnRD	0.006*** (3.72)	0.005* (1.74)	0.003 (0.78)	–	–	–
LnIO	–	–	–	0.011*** (5.64)	−0.021 (−0.52)	0.014* (1.63)
LnROA	−0.000 (−0.18)	0.000* (1.73)	−0.000 (−1.43)	−0.000 (−0.27)	0.000 (1.62)	−0.000 (−1.43)
LnROL	−0.000 (−0.67)	−0.000*** (−4.24)	0.000 (0.25)	−0.000 (−0.73)	−0.000*** (−4.50)	0.000 (0.25)
LnTAT	−0.062*** (−3.08)	−0.071*** (−3.50)	0.045 (1.19)	−0.070*** (−3.45)	−0.078*** (−3.74)	0.042 (1.12)
LnScale	−0.059*** (−12.36)	0.089*** (14.65)	−0.349*** (−23.53)	−0.063*** (−12.64)	0.102*** (14.76)	−0.356*** (−21.77)
_cons	2.025*** (18.64)	−1.244 (−9.16)	8.713*** (26.40)	2.123*** (18.91)	−1.463*** (−9.59)	8.847*** (24.77)
Sigma_u	0.088	0.106	0.388	0.083	0.119	0.388
Sigma_e	0.184	0.502	0.803	0.185	0.502	0.803
rho	0.185	0.043	0.189	0.170	0.053	0.190
R^2	0.034	0.012	0.051	0.031	0.013	0.052
F	38.09***	67.00***	130.78***	39.31***	64.68***	129.89***

provides potential applicable achievements, thus more conducive to improving enterprises production efficiency. Therefore, we can draw the conclusion that R&D investment plays the mediating role in the process of MER impact on GTFP and GTC, while innovation output plays a mediating role in the process of MER impact on GTFP and GEC.

Columns (4) and (5) of Table 3 show the estimation results of Eq. (4) and Eq. (5). In contrast to traditional cognition, it is interesting to find that MER's effect on RD and IO are both negative significant. It seems counterintuitive at first glance. However, the results also have certain rationality. Firstly, MER may increase enterprises production and operating costs, thereby resulting in a "Crowding Out Effect" on enterprises R&D and IO. Secondly, MER's influence on enterprises R&D and IO may have the lag period, resulting in a short-term negative impact. Thirdly, MER has a positive impact on GTP but a negative impact on RD and IO that can reflect enterprises innovation capability. MER may has a positive impact on other key variables that can influence enterprises innovation capability, and resulting in a "Masking Effect".

Combined all the regression results, MER shows significant influence on GTFP, GTC, GEC, RD and IO, RD shows significant influence on GTFP and GTC, IO shows significant influence on GTFP and GEC. Based on theory of examining the role of mediating variables [54], RD may play a mediating role in the process of MER impact on GTFP and GTC, IO may a mediating role in the process of MER impact on GTFP and GEC. To demonstrate these mediating effects, equations (6) and (7) were further tested, and the results are shown in Table 5.

The regression results indicate that after adding RD to the baseline regression model, MER still has a significant negative impact on GTFP at the 1 % level and a significant positive impact on GTC at the 1 % level. However, the negative impact is weakened and the positive impact is strengthened, while the indicator R^2 has been improved. That is, both in the process of MER affect GTFP and in the process of MER affect GTC, enterprise R&D investment shows an intermediating role. Similarly, when IO was added to the basic regression model, MER still had a negative significant impact on GTFP and GEC, but the negative impact was weakened and R^2 increased. This indicates that both in the process of MER affect GTFP and in the process of MER affect GEC, enterprise innovation output shows an intermediating role.

The mediating regression results indicate that MER has a "R&D Crowding Out Effect" on enterprises in the short term, but R&D investment and innovation output both have an "Innovation Compensation Effect" on enterprises green growth. Firstly, this result confirms the existence of "Follow Cost" theory in short term and expands the explanatory scope of this theory. Secondly, the empirical

Table 5
The mediate effect of RD and IO on the impact of MER affecting enterprise green growth.

Dependent variable	(1) LnGTFP	(2) LnGTC	(3) LnGEC	(4) LnGTFP	(5) LnGTC	(6) LnGEC
LnMER	−0.031*** (−2.79)	0.298*** (13.56)	–	−0.029*** (−2.70)	–	−0.585*** (−16.54)
LnRD	0.006** (3.71)	0.006* (1.98)	–	–	–	–
LnIO	–	–	–	0.011*** (5.45)	–	0.008 (0.89)
LnROA	−0.000 (−0.18)	0.000 (1.53)	–	−0.000 (−0.26)	–	−0.000 (−1.21)
LnROL	−0.000 (−0.64)	−0.000*** (−4.88)	–	−0.000 (−0.70)	–	0.000 (0.35)
LnTAT	−0.063*** (−3.13)	−0.062*** (−3.06)	–	−0.071*** (−3.50)	–	0.026 (0.70)
LnScale	−0.061*** (−12.48)	0.107*** (16.68)	–	−0.065*** (−12.72)	–	−0.388*** (−22.12)
_cons	2.089*** (18.49)	−1.866*** (−12.60)	–	2.181*** (18.79)	–	10.006*** (25.66)
Sigma_u	0.090	0.146	–	0.086	–	0.455
Sigma_e	0.184	0.499	–	0.185	–	0.796
rho	0.193	0.079	–	0.178	–	0.246
R^2	0.035	0.024	–	0.032	–	0.068
F	32.59***	72.88***	–	33.06***	–	122.74***

results clarifies the impact mechanism of MER on GTFP, and it can provide a theoretical basis for enterprises innovation and green development strategy.

Therefore, hypotheses 2a, 2b, 3a, and 3c have been confirmed. Overall, Hypothesis 2 and Hypothesis 3 are both partially supported.

All the above analysis help to clarify the impact mechanism and the research hypotheses are tested. Furthermore, effective routes are showed in the modified conceptual model in Fig. 1.

4.3. Robustness test

Robustness test is conducted by adding explanatory variables. There exist literatures propose that using the cross term estimation regression model can clarify the transmission mechanism, that is, adding the cross term of explanatory variables and mediating variables to the model for further regression analysis is essential. Therefore, this paper added MER and RD, MER and IO as the cross term respectively and carried out the regressions again. The empirical results are shown in Table 6. After adding new explanatory variables, the impact of the core explanatory variable on the dependent variable remains significant, and with a consistent influencing direction. Thereby, it confirms the robustness of the results.

The robustness test can also be carried out by reducing the sample. Pharmaceutical manufacturing enterprises are the knowledge and technology intensive economic entity, and its innovation capability is more significant. Therefore, we also carried out the robust test by using pharmaceutical manufacturing enterprises as subsamples. The results are shown in columns (1) to (4) in Table 7. According to the results, MER has a significant impact on enterprises green growth, enterprise R&D investment plays the mediating role in the impact process. Overall, the findings revalidated reliable and robust of research conclusions by using the new subsamples.

The long panel data is used in this study. In order to control the impact of time factor, this article further conducts robustness tests through time fixed effects analysis. Specifically, this article constructs a time trend term that set the first year of the sample as 1, and the subsequent years are extended accordingly. Then, it is controlled and we do the regression analysis again. The results are shown in columns (5) to (8) in Table 7. We can find that the regression results among variables remain stable. Thereby, the findings revalidated reliable and robust.

4.4. Heterogeneity analysis

This article further conducts heterogeneity analysis on the baseline regression of MER's directly impact on enterprises green growth.

4.4.1. Heterogeneity of industries

Different pollution circumstances among industries can affect the environmental supervision effect of MER policies. Therefore, based on the official classification standards, this article divides manufacturing enterprises into high, medium and low pollution industries, and further discusses the impact of MER on enterprise green growth in different industries. The regression results are shown in Table 8, Table 9 and Table 10. As shown in the regression results, MER continues to have a negative impact on GTFP, which is more significant in low pollution industries. MER continues to have a positive impact on GTC, which is more significant in moderately polluting industries. MER continues to have a negative impact on GEC, which is more significant in moderately polluting industries.

4.4.2. Heterogeneity of regions

As a country with vast territory, China has lots of regions, and there exists region heterogeneity. The economic development levels and resource endowments are significant different among different regions. Therefore, even if the same ER strategy is adopted, the

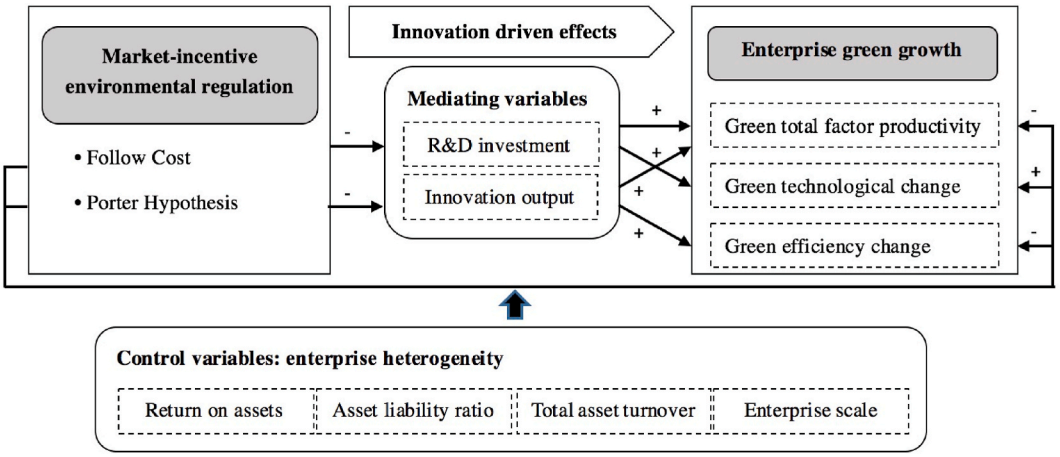

Fig. 1. The modified conceptual model.

Table 6
The robustness test, using the cross term.

Dependent variable	(1) LnGTFP	(2) LnGTC	(3) LnGEC	(4) LnGTFP	(5) LnGTC	(6) LnGEC
LnMER	−0.055*** (−4.28)	0.272*** (10.91)	–	−0.055*** (−4.60)	–	−0.607*** (−15.09)
LnMER *LnRD	0.06** (2.46)	0.006* (1.81)	–	–	–	–
LnMER *LnIO	–	–	–	0.013*** (5.37)	–	0.011 (1.15)
LnROA	−0.000 (−0.20)	0.000 (1.50)	–	−0.000 (−0.25)	–	−0.000 (−1.20)
LnROL	−0.000 (−0.64)	−0.000*** (−4.93)	–	−0.000 (−0.67)	–	0.000 (0.36)
LnTAT	−0.065*** (−3.24)	−0.064*** (−3.15)	–	−0.071*** (−3.53)	–	0.026 (0.69)
LnScale	−0.060*** (−12.30)	0.108*** (16.97)	–	−0.064*** (−12.70)	–	−0.388*** (−22.52)
_cons	2.096*** (18.63)	−1.857*** (−12.49)	–	2.186*** (18.82)	–	10.028*** (25.68)
Sigma_u	0.087	0.147	–	0.085	–	0.455
Sigma_e	0.185	0.499	–	0.185	–	0.796
rho	0.183	0.080	–	0.176	–	0.246
R^2	0.033	0.024	–	0.032	–	0.068
F	31.84***	72.73***	–	33.58***	–	122.91***

Table 7
The robustness test, reducing the sample and controlling the impact of time factor.

Dependent variable	(1) LnGTFP	(2) LnGTC	(3) LnGTFP	(4) LnGEC	(5) LnGTFP	(6) LnGTC	(7) LnGTFP	(8) LnGEC
LnMER	−0.029	0.336***	−0.029	−0.608***	−0.009	−0.030*	−0.009	0.036* (1.92)
	(−1.36)	(5.72)	(−1.45)	(−5.21)	(−0.79)	(−2.41)	(−0.75)	
LnRD	0.003***	−0.008*	–	–	0.005***	0.006***	–	–
	(2.75)	(−0.88)			(3.16)	(3.26)		
LnIO	–	–	0.013* (1.71)	−0.008	–	–	0.006***	0.129***
				(−0.22)			(2.91)	(2.86)
LnROA	−0.000	0.005* (1.62)	−0.001	−0.005	−0.000	0.000***	−0.000	−0.001**
	(−0.97)		(−1.35)	(−0.79)	(−0.14)	(3.20)	(−0.21)	(−2.15)
LnROL	0.000 (0.56)	0.002 (1.38)	0.001 (0.63)	−0.002	−0.000	−0.000*	−0.000	−0.001
				(−0.49)	(−0.27)	(−0.91)	(−0.31)	(−1.23)
LnTAT	−0.129***	−0.305**	−0.140***	0.008 (0.03)	−0.060***	−0.015*	−0.067***	−0.111***
	(−2.99)	(−2.30)	(−3.34)		(−3.31)	(−1.92)	(−3.66)	(−4.16)
LnScale	−0.057***	0.187***	−0.061***	−0.578**	−0.094***	0.004 (1.17)	−0.096***	−0.107***
	(−5.26)	(8.97)	(−5.51)	(−11.85)	(−12.26)		(−12.59)	(−7.52)
_cons	2.026***	−3.596***	2.108***	14.344***	2.833***	2.026***	2.892***	3.316***
	(8.18)	(−7.31)	(8.53)	(12.69)	(16.22)	(1.92)	(16.77)	(10.43)
Sigma_u	0.068	0.166	0.068	0.486	0.119	0.041	0.115	0.141
Sigma_e	0.135	0.494	0.135	0.798	0.182	0.192	0.183	0.385
rho	0.203	0.102	0.200	0.271	0.298	0.044	0.284	0.119
R^2	0.044	0.049	0.046	0.104	0.055	0.856	0.052	0.782
F	8.31***	20.26***	7.19***	30.75***	22.88***	17673***	22.09***	2783.0***

Table 8
Heterogeneity results of MER's impact on GTFP.

	Industry 1	Industry 2	Industry 3	Area 1	Area 2	Digital 1	Digital 2
LnMER	−0.046**	0.003 (0.16)	−0.052***	−0.032** (−2.35)	−0.033* (−1.87)	−0.044**	−0.028**
	(−2.12)		(−3.09)			(−2.26)	(−2.10)
LnROA	0.001* (1.74)	−0.000**	−0.003***	−0.001 (−1.08)	0.000 (0.36)	−0.002* (−1.80)	−0.000 (−0.10)
		(−2.10)	(−5.15)				
LnROL	0.000 (0.94)	0.000 (0.48)	−0.000***	0.000 (0.43)	−0.000**	0.000 (0.43)	−0.000 (−0.87)
			(−3.56)		(−2.13)		
LnTAT	−0.067***	−0.103***	−0.099***	−0.078***	−0.065 (−1.50)	−0.076***	−0.068***
	(−3.51)	(−4.24)	(−5.02)	(−6.41)		(−3.27)	(−2.74)
LnScale	−0.061***	−0.069***	−0.055***	−0.055***	−0.067***	−0.060***	−0.060***
	(−5.56)	(−6.93)	(−9.46)	(−10.69)	(−6.78)	(−8.56)	(−9.48)
_cons	2.136*** (8.63)	2.298*** (9.82)	2.029*** (15.14)	1.998*** (16.76)	2.285*** (9.53)	2.116*** (13.51)	2.100*** (14.26)
Sigma_u	0.085	0.096	0.082	0.078	0.097	0.084	0.084
Sigma_e	0.192	0.180	0.181	0.179	0.195	0.158	0.195
rho	0.164	0.221	0.172	0.158	0.196	0.219	0.156
R^2	0.029	0.040	0.049	0.029	0.035	0.043	0.027
F	8.00***	11.31	34.30***	29.26***	11.92***	23.78***	22.15***

Table 9
Heterogeneity results of MER's impact on GTC.

	Industry 1	Industry 2	Industry 3	Area 1	Area 2	Digital 1	Digital 2
LnMER	0.268*** (7.29)	0.374*** (9.28)	0.262*** (7.27)	0.128*** (5.12)	0.682*** (15.17)	0.296*** (7.44)	0.298*** (11.30)
LnROA	0.000 (0.78)	0.000 (0.79)	0.000 (0.19)	0.000 (0.42)	0.000** (2.41)	0.004*** (2.82)	0.000 (0.84)
LnROL	−0.000 (−0.04)	−0.000*** (−4.84)	−0.000*** (−3.95)	−0.000 (−0.96)	−0.000*** (−2.86)	−0.000 (−0.54)	−0.000*** (−4.86)
LnTAT	−0.022 (−0.89)	−0.137*** (−3.07)	−0.090** (−2.24)	−0.061** (−2.58)	−0.060* (−1.65)	−0.092** (−2.33)	−0.067*** (−2.80)
LnScale	0.096*** (8.29)	0.123*** (9.72)	0.105*** (11.43)	−0.101*** (12.31)	0.128*** (10.42)	0.114*** (9.42)	0.108*** (13.95)
_cons	−1.696*** (−6.12)	−2.214*** (−7.38)	−1.710*** (−7.92)	−1.579*** (−8.33)	−2.646** (−10.42)	−1.972*** (−7.17)	−1.850*** (−10.31)
Sigma_u	0.146	0.161	0.123	0.122	0.247	0.153	0.151
Sigma_e	0.399	0.494	0.558	0.507	0.479	0.526	0.487
rho	0.118	0.096	0.047	0.055	0.210	0.078	0.088
R^2	0.026	0.036	0.017	0.013	0.068	0.023	0.024
F	19.99***	40.17***	35.52***	40.50***	58.55***	28.69***	60.96***

Table 10
Heterogeneity results of MER's impact on GEC.

	Industry 1	Industry 2	Industry 3	Area 1	Area 2	Digital 1	Digital 2
LnMER	−0.387*** (−5.82)	−0.674*** (−9.04)	−0.663*** (−13.63)	−0.363*** (−11.32)	−1.110*** (−12.69)	−0.700*** (−12.06)	−0.545*** (−12.37)
LnROA	0.001 (0.56)	−0.000 (−1.44)	−0.000 (−0.01)	0.000 (0.44)	−0.000** (−2.25)	−0.001 (−0.27)	−0.000 (−1.17)
LnROL	0.001 (1.10)	0.001*** (4.50)	−0.001 (−1.28)	0.001* (1.99)	−0.000 (−0.32)	0.001 (0.77)	0.000 (0.29)
LnTAT	−0.034 (−0.76)	0.116 (1.37)	0.071 (0.85)	−0.001 (−0.03)	0.034 (0.63)	0.025 (0.30)	0.027 (0.66)
LnScale	−0.277*** (−10.85)	−0.436*** (−12.50)	−0.411*** (−18.24)	−0.387*** (−21.41)	−0.397*** (−12.97)	−0.432*** (−14.72)	−0.364*** (−18.80)
_cons	7.444*** (12.75)	11.096*** (13.64)	10.528*** (20.47)	9.815*** (23.76)	10.716*** (15.02)	11.092*** (16.65)	9.446*** (21.39)
Sigma_u	0.351	0.494	0.458	0.425	0.560	0.518	0.423
Sigma_e	0.651	0.810	0.865	0.808	0.766	0.826	0.782
rho	0.225	0.271	0.219	0.217	0.348	0.282	0.226
R^2	0.048	0.086	0.072	0.059	0.105	0.083	0.062
F	29.26***	52.59***	91.11***	105.33***	50.78***	62.21***	88.08***

effectiveness varies from place to place. Therefore, the environmental regulatory effects of MER policies are also different. Based on the official classification standards, this article divides the involved 31 provinces, autonomous regions, and municipalities in China into two major regions of eastern and central-western regions, then explores the impact of MER on enterprises green growth in different regions. The regression results are also shown in Table 8, Tables 9 and 10. Obviously, by comparison, in the economically developing central region and undeveloped western region, MER has more negative impact on GTFP and MER, and has a more positive impact on GTC. In the economically developed eastern region, MER has a more negative impact on GEC.

4.4.3. Heterogeneity of digital level

In today's digital era, digitalization shows a profound impact on enterprises green growth. And it is of great importance to analyze the impact of enterprises digital level on MER's environmental supervision effect. Python word frequency statistical analysis methods was used to measure sample enterprises digital level. Firstly, based on classic literature and policy documents, a topic lexicon is summarized. Secondly, through expert group discussions, 26 key words were formed to measure enterprises digital level, including networked, digitization, intelligent, informatization, big data, block chain, cloud computing, internet, internet-of-things, intelligent internet-of-things, integration, intelligent manufacturing, intelligent production, machine learning, virtual reality, virtual communities, smart enterprises, digital technology, digital empowerment, artificial intelligence, digital transformation, intelligence, digital assets, e-commerce, smart manufacturing and digital platforms. Thirdly, Python method was used to carry out the process of keywords "search-match-summary" base on sample companies' annual reports from 2011 to 2020. Fourthly, the digitalization level of the sample enterprises was quantitatively calculated, the relevant data are detailed in the attachments, and further divided enterprises digital level into two categories of low and high according to the median of 2020.

The subgroup regression results are shown in Table 8, Table 9, and Table 10. Obviously, MER has a negative impact on enterprises GTFP, and its impact on enterprises with high levels of digitalization is more apparently. MER has a positive impact on enterprises GTC, and its impact on enterprises with lower levels of digitalization is more apparently. MER has a negative impact on enterprises GEC, and its impact on enterprises with lower levels of digitalization is more apparently. The empirical results indicate that digitalization of enterprises increases operational costs, but at the same time promotes technological progress.

5. Conclusions, policy implications and limitations

5.1. Conclusions

Seeking green and sustainable growth is crucial for manufacturing enterprises achieving high-quality development, especially for developing countries like China, they are experiencing great pressure of eco protection and economic growth. In order to achieve green growth, the Chinese government has launched lots of ER measures. However, whether the regulations at the macro level can promote enterprises green growth at the micro level remains to be tested.

Thus, according to the existing theoretical and practical research literatures, and the above deep analysis, this paper establishes testable hypotheses on MER, enterprise innovation ability and enterprise green growth. According to 1220 Chinese manufacturing listed companies data during the period of 2011–2020, we can draw the conclusion that MER not only has a negative impact on enterprises current GTFP and GEC, but also has a positive impact on enterprises current GTC. Furthermore, the empirical results also indicate that enterprise R&D investment and enterprises innovation output both play the mediating role. That is, more R&D and IO input will decrease the negative impact of MER on enterprises GTFP, and increase the positive impact of MER on enterprises GTC.

Focusing on enterprises micro level, this article divides enterprises green growth into three sub-dimensions: GTFP, GTC and GEC. It is not only a valuable expand for current research from enterprise level, but also an in-depth discussion on enterprises green development and a beneficial supplement of MER's impact on enterprises green growth. The research results confirm that the "Follow Cost" effect is existing in the process of MER impact on GTFP and GEC, and there is a significant weak "Porter Hypothesis" in the process of MER impact on GTC. The empirical results confirm that both "Follow Cost" theory and the "Porter Hypothesis" are valid under certain conditions. The research findings have expanded the explanatory scope of "Follow Cost" theory and "Porter Hypothesis" theory. All these can provide theoretical supplementations and empirical supports for the rationality of the above two theories. The heterogeneous R&D and IO level of individual enterprises both play the intermediatary role in the process of MER impact on GTFP, GTC, and GEC. The environmental regulatory role of MER varies depending on enterprises type of industry, location, and digitalization level. The findings help to promote and deepen the related researches.

5.2. Policy implications

By clarifying the mechanism of MER on different indicators of enterprises green growth, it is not only helpful for policy makers to draft more appropriate regulations to promote enterprises green growth, but also helpful for enterprises to stimulate the innovation driven potentiality, then achieve sustainable development by adjusting appropriate R&D and IO level.

The research results can provide practical suggestions for policy-makers and enterprises. For the policy-makers: (1) In the short term, MER has a negative impact on GTFP and GEC, and has a positive impact on GTC. Therefore, the government needs to assess enterprises green growth from different dimensions, and develop a differentiated and comprehensive environmental regulatory system based on different green growth goals. (2) The heterogeneous R&D and IO level of individual enterprises both play a mediating role. Hence, the government should focus on improving enterprise R&D and IO level in the policy-making process, actively explore other effective environmental regulatory measures help enterprises achieve green development. (3) The environmental regulatory role of MER varies depending on enterprises type of industry, location, and digitalization level. Thus, the government should formulate heterogeneous MER measures based on these differences. From the perspective of enterprises, two aspects can be emphasized: (1) Enterprises GTFP can be achieved by improving enterprise R&D investment and innovation output. (2) Enterprises R&D investment can mainly affect GTFP and GTC while enterprises innovation output can mainly affect GTFP and GEC. Therefore, enterprises should formulate differentiated strategies to achieve green development based on their heterogeneity characteristics.

5.3. Limitations and future research

Firstly, we only included Chinese manufacturing listed companies 2010–2020 as the research samples, which limits the generalizability of research results in other contexts. Subsequent research can either expand the research samples such as including service industry enterprises or change the sample period to test the applicability of the findings. Secondly, this article explores the impact of MER on enterprises green growth in the current year, but the effectiveness of environmental regulations may have time lag or nonlinearity. Therefore, future researches can explore its long-term effects as well as possible nonlinear effects. Thirdly, in view of the limited research data, the three kinds of industrial wastes are at the city level, and then transformed into enterprise level. In the future, data calculation method should be more accurate, especially more accurate measurement of key indicators at the enterprise level should be carried on, which can further help to draw more scientifically research conclusions. Finally, digitalization presents both opportunities and challenges for enterprises green growth [55]. Time changing and technological evolution have brought new opportunities for enterprises green growth, and the role of digitalization on the enterprises green growth deserves attention. By way of digitization, enterprises can increase its data elements input, improve its production efficiency, promote the technology progress, and drive technology spillover [56–59]. Enterprise digitalization can directly affect green development, and can also indirectly affect green development through its impact on innovation. Consider this new background, future researches should further explore the role of digital level as the key variable.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Lu Liu: Writing – review & editing, Writing – original draft, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Kaiyuan Cui:** Writing – original draft, Supervision, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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