

Regulatory effect of improving environmental information disclosure under environmental tax in China: From the perspectives of temporal and industrial heterogeneity

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ABSTRACT

The environmental tax has been extensively examined as a well-accepted environmental policy. However, few studies have examined the regulatory effects of informal environmental regulation measures, such as environmental information disclosure (EID) under environmental taxes. This study uses an environmental computable general equilibrium (CGE) model to test this effect in China empirically. Our results show that improvements in EID have a “double dividend” regulatory effect of strengthening pollutant emissions reduction and stimulating economic growth under environmental taxes, but this effect displays significant temporal and industrial heterogeneities. The enhancing effect of EID on exhaust gas emissions reduction is more significant in the short run (−0.08% for SO₂; −0.08% for NO_x), whereas its economic stimulus effect is more prominent in the long run (0.09% for GDP). Nevertheless, improved EID has a weakening effect on wastewater discharge reduction. Improved EID quality can improve output for 64% and 93% of industries in the short and long term, respectively. However, significant non-uniformity is observed. In addition, improved EID quality can cause the energy consumption structure to shift from high-emissions coal toward other relatively cleaner alternatives in the long run. The study highlights that EID would be a beneficial supplement to formal environmental regulation measures.

1. Introduction

In recent years, China has implemented several environmental regulation measures to address the increasingly serious environmental pollution problems. According to the implementation agent, the measures can be divided into formal regulations promulgated by the government and informal regulations implemented by firms or the public (Féres and Reynaud, 2012; Zhao et al., 2015; Ren et al., 2018; Xiong and Wang, 2020). Environmental taxation has been accepted as an effective formal regulation measure to mitigate pollution (Ren et al., 2011; Liu

and Lu, 2015; Aubert and Chiroleu-Assouline, 2019). China's Environmental Protection Tax Law came into force on January 1, 2018, which strengthened the constraints of pollutant emissions reduction by formally changing pollutant discharge fees to environmental taxes. Nevertheless, it largely increases the production costs of heavy-polluting and energy-intensive sectors (Li et al., 2021). Environmental protection departments also motivate firms to raise environmental awareness through informal regulations, such as environmental information disclosure (EID). *The Guidelines for Environmental Information Disclosure of Listed Companies (Draft for Comments)* explicitly required the listed

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companies in 16 heavy-polluting industries to issue annual environmental reports and disclose environmental information, such as data on pollutant emissions (Ministry of Ecology and Environment of the People's Republic of China, 2010). Other listed companies can act on the principle of voluntary disclosure. Compared with environmental taxes, EID has the advantages of stronger flexibility, higher regulatory efficiency, and lower regulatory costs, making it more effective at stimulating the participation of companies in reducing pollutant emissions (Yu and Jin, 2021).

As a crucial informal environmental regulation measure, EID has a regulatory effect on pollutant emissions reduction and economic growth under environmental taxes. On the one hand, EID can exert a direct, positive regulatory effect on pollutant emissions reduction by motivating firms to increase investments in environmental protection and improve their emissions-reduction technology (Lin et al., 2021). On the other hand, improved EID increases the output of enterprises by promoting clean technology innovation and reducing financing costs (Luo et al., 2019; Feng et al., 2021), thus partially or completely offsetting the costs of environmental taxes. However, the increase in production indirectly weakens the pollutant emissions reduction effect of environmental taxation. Therefore, to achieve a “double dividend”, the EID’s direct pollutant emissions reduction effect should exceed its indirect pollutant emissions increasing effect driven by output expansion. Thus, discussing the impact mechanism between environmental taxes and EID helps clarify how EID makes a regulatory effect under formal regulations. In practice, environmental taxes and EID are the primary environmental regulation measures used to construct Chinese modern environmental governance systems. *The Guidance on Building a Modern Environmental Governance System* clearly stated that disclosing corporate environmental information and improving environmental protection legislations were both indispensable components of building a modern environmental governance system (The State Council of the People's Republic of China, 2020). Therefore, it is particularly important to quantify the regulatory effects of EID under environmental taxes for policymakers, which is conducive to building an integrated environmental governance system, including the government, corporations and the public.

Environmental taxation has attracted wide attention from scholars because of its pollutant emissions reduction effect and economic impact (Lu et al., 2010, 2019; Abdullah and Morley, 2014). Some studies suggested that environmental taxes would increase production costs and inhibit industrial output while reducing pollutant emissions, but the extent of the adverse economic impacts varied (Xie et al., 2018; Freire-González, 2018). For instance, Wang and Wei (2020) found that the environmental regulation was strictly implemented in emerging economies and showed a significantly adverse impact. However, other scholars proposed that the pollutant emissions reduction effect of environmental taxation was much greater than its restraint on economic development (Hu et al., 2021). Li and Masui (2019) concluded that implementing an environmental tax would substantially reduce China’s SO₂ emissions by 3.55% to 7.15%, by 2030 with a GDP loss of only 0.1%–0.2%. In addition, scholars suggested that tax rebates could be used to reduce the adverse economic impact of environmental taxation and might even produce a “double dividend” effect of both pollutant emissions reduction and economic growth (Ciaschini et al., 2012; Hu et al., 2018). For example, Xiao et al. (2015) found that recycling the environmental tax revenues to production tax and corporate income tax would offset 0.49% and 0.34% of GDP losses, respectively. Shi et al. (2019) also confirmed the existence of an environmental tax-generated “double dividend” by testing the effects of pollutant charges on the economy and environment.

As an essential supplement to formal environmental regulations, EID has been proven to have positive impacts on pollutant emissions reduction and firm productivity. The literature suggests that EID affects firm production in two main ways: First, it can promote pollutant emissions reduction by encouraging heavy polluters to improve their

energy efficiency and adopt clean production technology (Liu et al., 2010; Yin and Wang, 2018). According to the theory of social legitimacy, enterprises—under pressure from the government, consumers and other stakeholders—will constantly improve their EID to improve public goodwill and prove their “legitimacy” (Tzouvanas et al., 2020). The signal transmission theory also suggests that, to avoid the adverse selection risk caused by information asymmetry, heavy-polluting enterprises tend to improve the quality of their information disclosure, in order to transmit internal signals of their environmental performance to the market (Zhu and Zhang, 2012). Several scholars quantified how this process enhanced pollutant emissions reduction. Lin and Xie (2017) found that SO₂ emissions decreased by approximately 0.03% for every 1% increase in the EID quality using a GMM model. Wang et al. (2021) concluded that air quality information disclosure had a significantly negative impact on SO₂ emissions per unit of GDP. Second, as information holders, firms can provide environmental information to reduce the risks faced by investors, thus decreasing their financing costs (Li et al., 2017). Fonseka et al. (2019) concluded that, for every unit increase in EID, the equity capital cost of Chinese energy enterprises decreased by 0.33 units. Active EID can also reduce information asymmetry and credit mismatch risks between banks and firms, thereby reducing enterprises’ debt financing costs (Dhaliwal et al., 2011).

However, few studies discussed the interactions between informal and formal environmental regulation measures, particularly the regulatory effects of EID under environmental taxation. Some scholars argued that informal environmental regulations, especially public pressure, could reinforce the pollutant emissions reduction effect of coercive formal environmental regulations (Féres and Reynaud, 2012; Bae and Yu, 2018). Other studies suggested that the external institutional pressure exerted by formal environmental regulations could motivate polluters to take more active emissions reduction measures to improve the pollution control effect of informal environmental regulations (Kathuria, 2007; Jiménez-Parra et al., 2018). Some scholars found a two-way transmission mechanism between formal and informal environmental regulations, wherein they promoted and complemented each other (Xu et al., 2019; Tolmie et al., 2020). Thus, most studies discussed only how pollutant emissions reduction effects interacted between informal and formal environmental regulations, while the mechanism of their economic impacts was relatively unknown.

The current literature has several research gaps. First, studies have discussed the promotion of informal environmental regulations to the pollutant reduction effect of formal environmental regulations; however, their interactions in terms of the economic impact are still poorly understood. It is worth investigating whether informal environmental regulations reduce or increase the costs of formal environmental regulations, aside from the enhancing effect on pollutant emissions reduction. Second, although the enhancing effect of informal environmental regulations on pollutant emissions reduction has been examined, the temporal and industrial heterogeneity of these effects has not been analyzed in depth. Such heterogeneity may generate differences in the direction and extent of regulatory effects in the short and long terms and in various industries. Third, the literature has focused on econometric methods to analyze the interactions between informal and formal environmental regulations. This partial perspective cannot distinguish between direct and indirect mechanisms, nor can it reveal the differences in transmission mechanisms across industries. Additionally, the literature does not discuss the direct regulatory effects of EID under environmental taxes.

This study makes several contributions to the research. First, we clarify the direct impact mechanism of EID improvements on industries that disclose environmental information in the short and long run. The study reveals the direct impact path of EID on heavy-polluting industries, finding that it stimulates investment demand in the short term and increases capital stock in the long term. Second, this study examines the regulatory effect of EID under environmental taxes in China and identifies its temporal and industrial heterogeneities. Using the

computable general equilibrium (CGE) model, this paper investigates the regulatory effect of EID on pollutant emissions reduction and economic growth in the context of environmental taxes imposed, as well as its temporal and industrial heterogeneities. Third, this study elucidates the complementary relationship between EID and environmental taxes and between informal and formal environmental regulations, thus providing a reference that may assist in improving corporate social responsibility and building a modern environmental governance system.

The remainder of this paper is organized as follows. Section 2 illustrates Chinese environmental CGE model, economic data, and the establishment of a pollutant emission database. Section 3 describes model closures and the two scenarios used to verify the regulatory effects of improved EID quality under environmental taxes. Section 4 discusses the simulation results in terms of the macro-economy, wastewater discharge, exhaust gas emissions, and industrial output. Finally, Section 5 presents the conclusions and policy implications.

2. Data and methods

This study applies the CGE model to capture the direct and indirect regulatory effects of EID improvements on pollutant emissions reduction and economic impact in the context of environmental taxes, as well as the transmission mechanism across industries. The Chinese environmental CGE model is based on the ORANIG model (Horridge, 2014), jointly developed by Institutes of Science and Development, Chinese Academy of Sciences, and the Center of Policy Studies (CoPS) of Victoria University, Australia. The CGE model includes modules for production, investment demand, household consumption, government consumption, and exports. The environment module and the account of pollutant emissions are embedded within it.

2.1. Economic module

The economic module includes production, demand, and equilibrium. The equation for each part is described below.

- (1) Structure of production. Input decision-making and output distribution are the key industry activities. The manufacturer chooses its best inputs to minimize the production costs given the output, and allocates its output to the domestic and export market according to the principle of profit maximization. This study uses the multi-input nested structure described by Hu et al. (2018; see Fig. 1). At the top level, commodity composites, a primary factor composite, and energy composites are combined using a Leontief production function. At the second level, each commodity composite is a constant elasticity of substitution (CES) function of a domestic good and the imported equivalent. The primary factor composite is a CES aggregate of land, capital and labor. The energy composites are divided into coal, oil and gas, coke, electricity, natural gas, and refined oil, which are also incompletely substituted in the form of a CES function. In addition, each energy composite is the third level of the CES function of a domestic good and the imported equivalent. Equation (1) is the top-level nested function; equations (2) to (4) reflect the second-level nested function for intermediate input, primary factors, and energy, respectively; and equation (5) is the third-level nested function for energy products:

$$X1_S(c, i) = CES \left[All, s, SRC : \frac{X1(c, s, i)}{A1(c, s, i)} \right], SRC = \{dom, imp\} \quad (2)$$

$$FAC(i) = CES \left[\frac{X1LAB(i)}{A1LAB(i)}, \frac{X1CAP(i)}{A1CAP(i)}, \frac{X1LND(i)}{A1LND(i)} \right] \quad (3)$$

$$X1_energy(i) = CES \left[All, e, ECOM : \frac{X1energy_S(e, i)}{A1E_S(e, i)} \right], ECOM = \{1, \dots, M\} \quad (4)$$

$$X1energy_S(e, i) = CES \left[All, s, SRC : \frac{X1energy(e, s, i)}{A1E(e, s, i)} \right], SRC = \{dom, imp\} \quad (5)$$

where i , c , and s denote the industry, commodity, and source, respectively. $X1TOT(i)$ is the total output of industry i , $X1_S(c, i)$ is the intermediate input of product c of industry i , and $FAC(i)$ is the primary factor input of industry i , consisting of labor $X1LAB(i)$, capital $X1CAP(i)$, and land $X1LND(i)$. $X1_energy(i)$ is the energy input of industry i , and $G1(i)$ denotes the Hicks-neutral technical change terms that affect all inputs. $A1_F(i)$, $A1_E(i)$, and $A1_S(c, i)$ are the technical change terms of primary factors, energy, and commodity c (without distinguishing between sources) used in the production of industry i , respectively.

- (2) Investment demand. The nesting structure of the investment demand is similar to that of production. The manufacturer selects the best investment product portfolio based on the principle of cost minimization to form the current capital required by the industry. It is assumed that investment is formed by the input of domestic and imported products, without the direct use of primary factors. The functional forms are as follows:

$$X2TOT(i) = \frac{1}{G2(i)} * MIN \left[All, c, COM : \frac{X2_S(c, i)}{A2_S(c, i)} \right], COM = \{1, \dots, N\} \quad (6)$$

$$X2_S(c, i) = CES \left[All, s, SRC : \frac{X2(c, s, i)}{A2(c, s, i)} \right], SRC = \{dom, imp\} \quad (7)$$

where $X2TOT(i)$ is the total investment in industry i , $X2_S(c, i)$ is the input of investment product c that forms a new investment in industry i , $G2(i)$ is a neutral technical change term, and $A2_S(c, i)$ is the technical change term of investment product c (without distinguishing between the sources) used in the investment in industry i .

- (3) Household demand. The household consumption module includes the household utility function and budget constraints, which satisfy the assumption of utility maximization. Equation (8) is used to maximize the Klein–Rubin (Stone–Geary) utility function subject to the household's budget constraints, and Equation (9) is the linear expenditure system (LES) after the utility maximization problem is solved. Equation (10) indicates that the household consumption of a certain commodity is a CES function for domestic and imported goods:

$$MAXU = \prod_{c=1}^N \left[\frac{X3_S(c)}{Q} - A3SUB(c) \right]^{\beta(c)} \quad s.t. \sum_c \frac{X3_S(c)}{Q} * P3_S(c) = \frac{Y}{Q} \quad (8)$$

$$X1TOT(i) = \frac{1}{G1(i)} * MIN \left[All, c, COM : \frac{X1_S(c, i)}{A1_S(c, i)}, \frac{FAC(i)}{A1_F(i)}, \frac{X1_energy(i)}{A1_E(i)} \right], COM = \{1, \dots, N\} \quad (1)$$

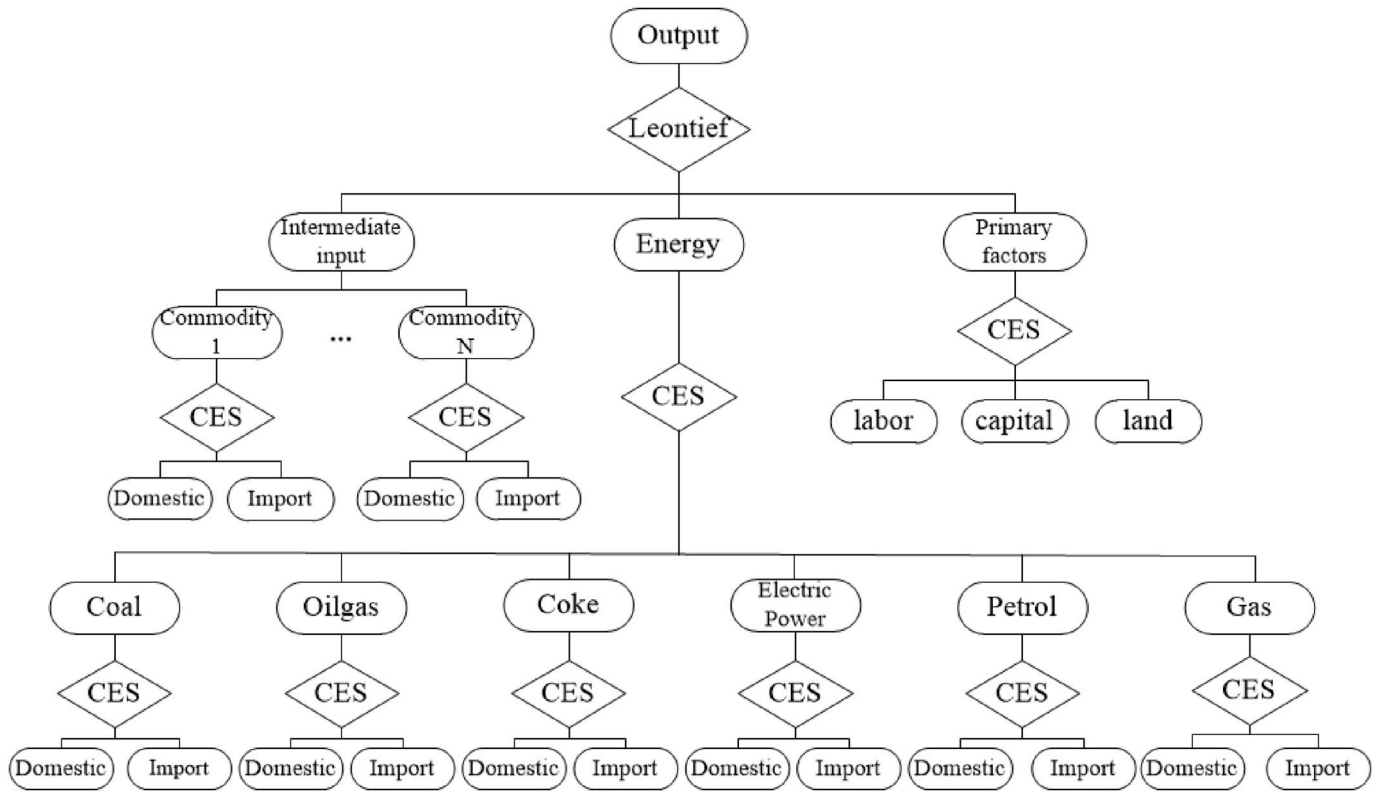


Fig. 1. Nested production structure of the environmental CGE model.

$$X3_S(c) = X3SUB(c) + \frac{\beta(c)}{P3_S(c)} * \left[Y - \sum_{c=1}^n X3SUB(c) * P3_S(c) \right] \quad (9)$$

$$X3_S(c) = CES \left[All, s, SRC : \frac{X3(c, s)}{A3(c, s)} \right], SRC = \{dom, imp\} \quad (10)$$

where U is household utility, Y is household disposable income, and Q is the number of households. $X3_S(c)$ is the total consumption of commodity c by households, $X3SUB(c)$ is the subsistence requirement of commodity c , and $P3_S(c)$ is the purchasers' price. $\beta(c)$ is the marginal budget share of commodity c , and $A3SUB(c)$ is the individual household's subsistence demand for commodity c . $X3(c, s)$ is the household consumption of commodity c from source s , and $A3(c, s)$ is the household taste.

- (4) Export demand. Commodities are classified as tradable or non-tradable. The export demand for non-tradable products is mainly affected by government policies and has little relationship with their market prices, while the export demand for tradable products has a reverse relationship with their prices. The equation is as follows:

$$X4(c) = F4Q(c) \left[\frac{P4(c)}{PHI * F4P(i)} \right]^{EXP_E(c)} \quad (11)$$

where $X4(c)$ is the export volume of commodity c , $P4(c)$ is the export FOB price in local currency, PHI is the nominal exchange rate under the indirect pricing method, $F4Q(c)$ and $F4P(c)$ allow for horizontal (quantity) and vertical (price) shifts in the demand schedules, respectively, and $EXP_E(c)$ is the constant elasticity of export demand.

- (5) Equilibrium module. Three characteristics emerge when the model is in equilibrium: market clearing, a zero-profit condition for the manufacturer, and a balance of payments. Market-clearing signifies that supply and demand are equal in the commodity and factor markets. Zero profit requires that the price accepted by the manufacturer is equal to the cost price, and the purchasers' price is equal to the cost price plus taxes and circulation costs in the sales process. The balance of payments includes the balance of investment and savings, government payments, and international payments.

2.2. Economic data

We establish the database of our CGE model based on the 2012 input-output tables of China published by the National Bureau of Statistics, the database establishment method of the 2002 input-output tables of China developed by the CoPS (Horridge and Wittwer, 2008), and the development method used for the Chinese database in the ninth version of the GTAP model (Aguilar et al., 2016). It comprises 139 sectors (five sectors of agriculture, forestry, animal husbandry, and fishery; 93 industrial sectors; four sectors of the construction industry; and 37 sectors of the service industry), three primary factors (labor, capital, land), six economic entities (production, investment, households, government, foreign countries, inventory), and eight types of circulation services (sea transport, air transport, railway, road, pipeline transport, insurance, trade [wholesale and retail], and warehouse storage). GEMPACK software was used for the database establishment (Horridge et al., 2018). The parameters in our CGE model include substitution elasticity, price elasticity, and expenditure elasticity, which are mainly set with reference to the values of the Chinese database in the ninth version of the GTAP model (Aguilar et al., 2016). Specifically, the elasticity of substitution among the three primary factors is 0.5, and the price elasticity of

export demand for tradable goods is 4; the range of Armington substitution elasticity between domestic and imported intermediate inputs is 0.9–5.6, with an average value of 2.95; the elasticity of substitution among different energy products is 0.5, and the range of household expenditure elasticity for different commodities is 0.2–2.1, with an average value of 1.05.

2.3. Environmental module

The pollutant emission module includes two types of exhaust gases (SO₂ and NO_x) and wastewater (COD and NH₃). The total emissions of the exhaust gas are equal to the sum of the combustion and process emissions. The combustion emissions considered are pollutant gas emissions caused by industries or households burning fossil energy in the production or living processes. The equations are as follows:

$$BE_{(g,i,e,s)} = a_{(g,i,e,s)} * ED_{(i,e,s)} \quad (12)$$

$$BE_{(g,h,e,s)} = a_{(g,h,e,s)} * ED_{(h,e,s)} \quad (13)$$

where g is the exhaust gas, including SO₂ and NO_x, i is the industry (including 139 sectors), e is the energy (including coal, oil and gas, coke, electricity, natural gas, and refined oil), s is the source (including domestic and imported goods), and h is the household. $BE_{(g,i,e,s)}$ and $BE_{(g,h,e,s)}$ are the exhaust gas g generated by industry i and household h using energy e from source s , $ED_{(i,e,s)}$ and $ED_{(h,e,s)}$ are the demand of industry i and household h for energy e from source s . $a_{(g,i,e,s)}$ and $a_{(g,h,e,s)}$ are the combustion emissions coefficients of industry i and household h .

The process emissions of exhaust gas are produced by an enterprise using a particular manufacturing technique. This is generally related to the output of the enterprise. The equation is as follows:

$$PE_{(g,i)} = b_{(g,i)} * Q_i \quad (14)$$

where $PE_{(g,i)}$ is the process emissions of g generated by industry i , $b_{(g,i)}$ is the process emissions coefficient of g generated by industry i , and Q_i is the output of industry i .

Wastewater discharge comprises industrial and household discharge processes. We assume that the wastewater discharge of an industry is related to its output, while that of a household is related to its consumption. The equations are as follows:

$$PW_{(w,i)} = c_{(w,i)} * Q_i \quad (15)$$

$$PW_{(w,h)} = c_{(w,h)} * Q_h \quad (16)$$

where w is the wastewater, including NH₃ and COD. $PW_{(w,i)}$ and $PW_{(w,h)}$ are the wastewater discharge volumes of industry i and household h , respectively; $c_{(w,i)}$ and $c_{(w,h)}$ are the wastewater process discharge coefficients of industry i and household h ; Q_i and Q_h are the output of industry i and the consumption of household h , respectively.

2.4. Establishment of pollutant emission database

The pollutant emissions database is based on the 2007 China pollution source census data, the 2013 China Environmental Statistics Yearbook, and the 2012 database from Chinese Academy of Environmental Planning. These data have been widely used in research in environmental regulations (Wang and Shen, 2016; Wang and Zhang, 2020). The above pollutant emission data must be matched with the 139 sectors in the 2012 China input-output tables. The data processing procedure is described below.

The basic method of processing exhaust gas emission data is to take the emissions of each sector as noted in China Environmental Statistics Yearbook as the total amount and proportion of sub-sector pollutant emissions as the structure. The equations are as follows:

$$E_i = Q_R * S_i \quad (17)$$

where E_i denotes the exhaust gas emissions of industry i , Q_R denotes the exhaust gas emission of each sector in China Environmental Statistics Yearbook (including 30 industries in 2012), and S_i is the emission structure:

$$S_j^1 = \frac{P_j}{P_J} (j \in J) \quad (18)$$

$$S_k^2 = \frac{w_k * ED_k}{P_K} (k \in K) \quad (19)$$

$$S_c^3 = \frac{w_{ave} * ED_c}{P_C} (c \in C) \quad (20)$$

Various pollutant emission structures are selected for different industries based on data availability. (1) S_j^1 is the exhaust gas emission structure of the industrial sector, P_j denotes the exhaust gas emissions of industrial sub-sector j in the database from Chinese Academy of Environmental Planning (including 93 industrial sub-sectors except for the construction industry), and P_J denotes the exhaust gas emissions of sector J to which sub-sector j belongs. (2) S_k^2 is the exhaust gas emission structure of agriculture, transportation, wholesale and retail, and other service industries. w_k is the exhaust gas emission intensity of sub-sector k as reflected in China pollution source census data, ED_k is the total fossil energy input of sub-sector k in 2012, and P_K denotes the exhaust gas emissions of industry K to which sub-sector k belongs. (3) S_c^3 is the exhaust gas emission structure of the construction industry, is the average exhaust emission intensity of all non-construction industries as reflected in China pollution source census data, ED_c is the total fossil energy input of sub-sector c of the construction industry in 2012, and P_C denotes the exhaust gas emissions of industry C to which sub-sector c belongs. The method described above generates data on exhaust gas emissions for each sector in the 2012 China input-output tables. The processing method for the wastewater discharge data is similar to that used for the exhaust gas emissions data.

3. Design of simulation scheme

3.1. Model closures

The short and long-run closures are set to compare the temporal heterogeneity of the regulatory effect of EID improvements under environmental taxation. In the short-run closure, (1) the real wage remains unchanged because of price stickiness, but labor can move freely among sectors, and total employment is endogenous. (2) The capital stock is fixed and cannot flow freely among sectors. This means that the rate of return on investment in each sector is different, so investments will differ across sectors. (3) Household consumption is determined by income. Additionally, government expenditure and technological progress remain unchanged.

In contrast to short-run closures, long-run closures can reflect the impact of capital stock accumulation. In the long-run closure, (1) the total amount of labor remains unchanged, but it can flow freely among various sectors. (2) The capital stock is endogenous and can flow freely among sectors. This means that capital has adequate time to adjust so that it flows to sectors with a higher rate of return, ultimately making the rate of return on investment in each sector equal. In addition, investments change in proportion to the capital stock. (3) Household consumption and government expenditure are endogenous and change in the same proportion. The trade balance item changes in proportion to GDP. Moreover, technological progress remains unchanged exogenously.

3.2. Scenarios

Two scenarios are compared to examine the regulatory effect of improvements in the EID quality under environmental taxes. Environmental tax (ET) is set as the benchmark, and the combination of environmental tax and environmental information disclosure (ETID) as the policy scenario. This is done for two reasons: First, environmental tax is set as a benchmark to evaluate the pollutant emissions reduction and economic impacts of levying an environmental tax at the current rate. Second, by comparing the changes in economic indicators and pollutant emissions between the case when EID improvement is considered and the case when it is not, the direction and extent of the regulatory effect of EID improvement under environmental taxes can be accurately identified.

- (1) In the ET scenario, we impose an environmental tax on all sectors (except the agricultural sector). An environmental tax is introduced into the CGE model through an ad valorem tax. However, the current tax collection is based on the pollution equivalent value, which is a specific duty. The following formula is used to convert the specific duty to the ad valorem tax:

$$T_g^* E_{(g,i,s)} = BT_g^* t_{(g,i)} \quad (21)$$

where g, i , and s are the pollutants, industry, and source, respectively. T_g is the specific duty of pollutant g , $E_{(g,i,s)}$ is the emissions amount of pollutant g (unit: ton) from source s of industry i , BT_g is the ad valorem tax base of pollutant g , and $t_{(g,i)}$ is the ad valorem tax of pollutant g levied on industry i .

The object, coverage, and rate of environmental taxes should be clarified. (1) China's environmental tax is levied only on firms, not households. (2) The tax does not include agriculture. (3) At the national level, the tax is obtained by a weighted average of the provincial environmental tax (see Appendix A), and the weight is the proportion of the pollutant emissions of each province to the total pollutant emissions of China. It is worth stating that the study area of this research is only mainland China, because data from Hong Kong, Macao and Taiwan are not available. After this calculation, the weighted average environmental taxes for SO₂, NO_x, COD, and NH₃ are 3,248, 3,460, 3,953, and 3,098 yuan/ton, respectively.

- (2) In the ETID scenario, we introduce the impact of EID on the basis of the ET scenario. It should be noted that EID improvements refer to both the quantity and quality of environmental information, and this study focuses on the impact of improvements in EID quality. Three dimensions are commonly chosen to rate the quality of EID, including salience, quantification and temporality (Shen et al., 2010). Although the Chinese government currently requires listed firms from heavy-polluting industries to release their environmental reports, the impact of non-listed firms that voluntarily disclose their environmental information should also be considered. Thus, we investigate the impact of EID from an industry-level perspective.

As mentioned, the main impact paths of EID include encouraging technological progress (improvements in energy efficiency and process emission factors) and reducing financing costs. Specifically, the equations and impact mechanisms of EID quality improvement's effect on investment are as follows:

$$RORC_i = \frac{PK_i}{\pi_i} - d_i \quad (22)$$

$$RORE_i = RORC_i \left(\frac{KE_i}{KB_i} \right)^{-\beta} \quad (\beta > 0) \quad (23)$$

$$KE_i = KB_i * (1 - d_i) + I_i \quad (24)$$

After the above equations are linearized, the relationship between the capital growth rate and the rate of return on investment is obtained as follows:

$$KG_i = finv_i + \frac{1}{G^*\beta} * \{Q^*[RORC_i + fRORC_i] - invslack\} \quad (25)$$

where i is the heavy-polluting industry that discloses environmental information; $RORC_i$ is the current rate of return on investment of industry i ; PK_i is the capital price; π_i is the price of investment goods; d_i is the depreciation rate; $RORE_i$ is the expected rate of return on investment; KE_i is the ending capital stock; KB_i is the initial capital stock; I_i is the new investment; KG_i is the capital growth rate; G is the ratio of investment to the ending capital stock; Q is the ratio of the total rate of return on investment ($RORC_i + d_i$) to the net rate of return; $finv_i$ is a preference variable; and $invslack$ is a slack variable. We refer to the ORANIG model (Dixon et al., 1982; Horridge, 2014) for the parameters $\frac{1}{G^*\beta} = 0.33$, $G = 0.3$, $\beta = 10$, $Q = 2.0$. The exogenous variable $fRORC(i)$ is added to characterize the change in the financing cost in the short run. If the financing cost decreases, $fRORC(i) > 0$; whereas if the financing cost increases, $fRORC(i) < 0$.

The mechanisms through which improvements in EID quality affect investment in the short and long run are shown in Fig. 2(A) and Fig. 2 (B), where $E0$ is the initial equilibrium point. At this time, the rate of return on investment in industry i is equal to its financing cost. The financing cost of industry i decreases if it improves EID quality. Thus, it has motivation to expand investment and production capacity. In the short run, the new investment in industry i equals the level of capital formed in the long run, reducing the expected rate of return to the new financing cost $RORE_i^*$. $E1$ is the short-run equilibrium point. In the long run, the actual capital will be accumulated in industry i because investment can be transformed into production capacity; thus, capital stock will increase until the rate of return on investment drops to the new financing cost $RORE_i^*$, and, finally, a long-run equilibrium point $E2$ is formed. In summary, since a period of time elapses from the company's planned investment to the formation of capital stock, improvements in EID will increase investment in specific industries in the short run. However, it will convert into new capital accumulation and production capacity in the long run.

The study draws on empirical results in the literature on the impacts of EID improvements on pollutant emissions reduction and financing costs for the treatment of shocks. (1) According to the *Guidelines for Environmental Information Disclosure of Listed Companies (Draft for Comments)*, the most heavy-polluting industries are thermal power, iron and steel, cement, electrolytic aluminum, coal, metallurgy, chemical industry, petrochemicals, building materials, papermaking, brewing, pharmaceuticals, fermentation, textiles, leather, and mining sectors. These 16 industries are matched with the 56 sectors listed in the 2012 input-output tables of China (see Appendix B). (2) We assume that the EID quality increases by 1% in the ETID scenario. Regarding technology shocks, every 1% increase in EID quality will result in a decrease of 0.03% in SO₂ and wastewater discharge (Lin and Xie, 2017). Tian et al. (2016) also found that, for every 1% increase in EID quality, the emission intensities of COD, NH₃, and SO₂ decreased by 0.3%, 0.22%, and 0.16%, respectively. Therefore, this study takes an average of 0.1% as the improvement rate for energy efficiency and the process emissions coefficient of exhaust gas, and takes an average of 0.17% and 0.13% as the improvement rate for the process emissions coefficient of COD and NH₃, respectively. Regarding the financing costs shock, we follow Shen et al. (2010) and Yuan (2014), who indicated that, for every 1% increase in EID quality, financing costs decreased by 0.4%.

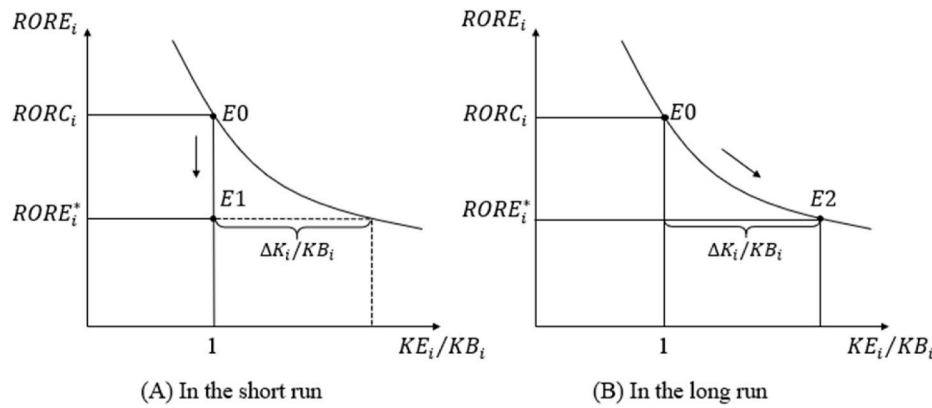


Fig. 2. Impact mechanism of EID quality improvement on investment.

4. Simulation results and analysis

This study analyzes the regulatory effect of EID on the macro-economy, wastewater discharge, exhaust gas emissions, and industrial output under environmental taxation. The regulatory effect of EID improvement on pollutant emissions reduction and economic growth under environmental taxes has two channels: The first channel motivates enterprises to improve their energy efficiency or production processes by increasing investments in facilities or in research and development, thus reducing wastewater and exhaust emissions and enhancing the effect of environmental taxation on pollutant emissions reduction. However, technological advances lead to output expansion and increased pollutant emissions. The second channel reduces financing costs and stimulates enterprise investment and output increases, partially offsetting the economic losses caused by environmental taxes, but this weakens their pollutant emissions reduction effect. The direction and extent of the EID's regulatory effect under environmental taxes depend on the joint effects of these two channels.

Overall, improved EID has a positive regulatory effect of strengthening pollutant emissions reduction and boosting economic growth under environmental taxation, but it has significant temporal heterogeneity. Improvement in EID has a greater stimulus effect on the economy in the long term than in the short term, but the enhancing effect on pollutant emissions reduction is weaker in the long term. Meanwhile, EID improvement's stimulus effect on pollutant emissions reduction is greater than its effect on economic improvement in the short term, but its enhancing effect on pollutant emissions reduction is weaker than its effect on economic growth in the long term.

4.1. Regulatory effect on macro-economy

The core transmission mechanism among the economic variables in the CGE model can be described through a set of simplified linkage equations, which is defined as a back of the envelope (BOTE) analysis (Dixon and Rimmer, 2013). For a detailed discussion of the impact mechanism of EID improvement on the macro-economy in the short and long terms based on a BOTE analysis, refer to Appendix C. As shown in Table 1, improved EID quality can reduce the economic loss caused by an environmental tax and improve employment. Its positive effect on GDP is of the greatest significance in the long term. With the EID quality improved by 1%, the GDP loss caused by an environmental tax in the short term is reduced to 0.16%, which recovers 0.04%. The primary cause for this is that, by reducing social financing costs and improving energy efficiency and production processes, the improved EID encourages enterprises to increase investment and expand production, thus reducing the economic cost of the environmental tax. Improvements in EID stimulate enterprise investment and production, and promote employment in the short term; the decline in employment shrinks to

0.3%, recovering 0.03%. In the long term, labor supply is exogenous, and its impact on the factor market is mainly reflected in the effect on the labor price, which increases by 0.18%.

Improved EID also raises the price of domestic factors of production, which will bring more pressure on the CPI in the short term. In addition, improvements in EID reduce the financing cost of enterprises, stimulate an increase in investment demand, and increase the output of industries that produce investment goods. Since most of these industries are capital-intensive and the capital stock is fixed in the short term, this will promote an increase in capital prices. Meanwhile, the expansion of output caused by technological progress will also boost the demand for factors, eventually leading to increases in the prices of labor and capital factors of 0.07% and 0.14%, respectively, and increasing the CPI by 0.07%. In the long term, the CPI only slightly increases by 0.03% (see Table 1), primarily because with investment continuously converted into production capacity in the long term, capital stock increases, and the capital price decreases by 0.14%, which alleviates the increase in CPI.

Improved EID can boost domestic demand, which has a more significant driving effect on investment in the long term. In the short run, the expansion of the economic scale promotes the growth of total income; therefore, household consumption increases by 0.04%. The decrease in financing costs also contributes to a 0.14% increase in investment demand. In the long run, as capital stock increases, investment expands further to 0.16% (see Table 1). Although it is necessary to increase domestic savings by reducing consumption of households and the government to meet the investment demand in the long run, the driving effect of the increase in GDP on consumption demand is greater than the crowding-out effect of the increase in investment. This eventually leads to an increase in household consumption of 0.02%, and government expenditure increases in the same proportion as household consumption.

Improvements in EID have strong temporal heterogeneity in the adjustment of external demand. Net exports decline in the short term but trend upward in the long term. Imports increase by 0.04%, and exports decrease by 0.12%, influenced by the improvement in EID in the short term. The increase in imports is primarily due to the overall expansion of the economic scale. However, the prices of domestic products increase, and their international competitiveness weakens because factor prices are pushed up in the short run, resulting in a decline in exports. By contrast, exports improve significantly, but imports decline in the long run, due to the substantial reduction in the price of capital factors, which gives domestic products more comparative advantages. As shown in Table 1, the demand for imports decreases slightly, and exports increase by 0.04%, owing to the improvement in EID in the long term.

Table 1

Comparison between regulatory effect of EID on macro-economy in the short and long term (unit: %).

	Short term			Long term			Short & Long term (difference)
	ET	ETID	ETID-ET	ET	ETID	ETID-ET	ETID-ET
Real GDP	-0.192	-0.155	0.037	-0.190	-0.103	0.087	0.050
Employment	-0.327	-0.299	0.028	0.000	0.000	0.000	-0.028
CPI	-0.208	-0.140	0.068	-0.106	-0.080	0.026	-0.042
Price of Labor	-0.208	-0.140	0.068	-0.808	-0.627	0.181	0.113
Price of Capital	-1.033	-0.889	0.143	0.065	-0.077	-0.142	-0.286
Investment Demand	-0.588	-0.450	0.138	-0.428	-0.272	0.156	0.018
Household Consumption	-0.170	-0.132	0.038	0.040	0.063	0.023	-0.015
Government Expenditure	0.000	0.000	0.000	0.040	0.063	0.023	0.023
Imports	-0.290	-0.254	0.036	-0.0898	-0.0903	-0.0004	-0.037
Exports	0.277	0.160	-0.117	-0.172	-0.137	0.036	0.152

Table 2

Comparison between regulatory effects of EID on exhaust emissions in the short and long term (unit: %).

		Short term			Long term			Short & Long term (difference)
		ET	ETID	ETID-ET	ET	ETID	ETID-ET	ETID-ET
SO ₂	Total Emissions	-1.289 (-32.879)	-1.370 (-34.944)	-0.081 (-2.065)	-1.363 (-34.754)	-1.378 (-35.137)	-0.015 (-0.383)	0.066 (1.682)
	Industrial Emissions	-1.381 (-32.374)	-1.477 (-34.637)	-0.097 (-2.263)	-1.481 (-34.729)	-1.503 (-35.240)	-0.022 (-0.511)	0.075 (1.752)
	Household Emissions	-0.246 (-0.505)	-0.150 (-0.307)	0.096 (0.197)	-0.012 (-0.025)	0.050 (0.103)	0.062 (0.128)	-0.034 (-0.070)
NO _x	Total Emissions	-1.024 (-25.987)	-1.100 (-27.905)	-0.076 (-1.917)	-1.097 (-27.829)	-1.111 (-28.194)	-0.014 (-0.365)	0.061 (1.552)
	Industrial Emissions	-1.073 (-25.599)	-1.159 (-27.667)	-0.087 (-2.068)	-1.165 (-27.805)	-1.186 (-28.290)	-0.020 (-0.486)	0.066 (1.582)
	Household Emissions	-0.256 (-0.389)	-0.157 (-0.238)	0.099 (0.151)	-0.016 (-0.024)	0.063 (0.096)	0.079 (0.120)	-0.020 (-0.031)

Note: Change in level value (unit: 10,000 tons) is shown in parentheses.

4.2. Regulatory effect on pollutant emissions

An improvement in EID has an enhancing effect on exhaust emissions reduction, but the effect is weaker in the long term than in the short term. The total emissions of SO₂ and NO_x in the short term will further decrease by 0.081% (20,650 tons) and 0.076% (19,170 tons) when the EID improvement is considered. In the long term, the emissions of these two types of exhaust gases will decrease by 0.015% (3,830 tons) and 0.014% (3,650 tons), respectively, which are 0.06% and 0.07% lower than those in the short term (see Table 2). This difference occurs mainly due to the difference between the short and long-term major impact mechanisms. In the short term, the incentive effect of EID improvement in heavy-polluting industries on enterprises' energy efficiency and production process improvement plays a leading role, which causes a reduction in the demand for coal, oil, gas, and other energy in these industries, thus reducing exhaust emissions. However, the declining financing cost in the long term has a more pronounced stimulus effect on investment and production, which allows the economy to expand further and results in an increase in exhaust emissions. In terms of emitters, there is a significant difference in the direction of the EID's regulatory effect on exhaust emissions reduction between the industry and households: There is an enhancing effect on pollutant emissions reduction for the industry, but there is a weakening effect for households. The increase in household pollutant emissions is mainly due to the expansion of household consumption.

Furthermore, improvements in EID have a weakening effect on wastewater discharge reduction. In the short term, they slightly increase total COD and NH₃ emissions by 0.001% (140 tons) and 0.01% (250 tons), respectively; in the long term, they increase the total COD and NH₃ emissions by 0.006% (1,500 tons) and 0.012% (320 tons; see Table 3), respectively. As with the impact mechanism of exhaust emissions, the directions in the regulatory effect of EID improvement differ between industrial and household wastewater emissions reduction.

Influenced by the expansion in economic scale in both short and long term, household consumption increases, and household wastewater discharge also increases. The increase in household wastewater discharge is greater than the decline in industrial wastewater discharge; hence, the overall wastewater discharge shows an increasing trend.¹ It is observed that the increment in household pollutant emissions is an important factor that weakens the regulatory effect of EID on pollutant emissions reduction.

4.3. Regulatory effect on industrial output

Improvements in EID quality can increase the output of heavy-polluting industries, driven by investment in the short term and a decline in capital prices in the long term. It also has an impact on upstream and downstream industries through the industrial linkage effect. Improvements in EID benefit 64% of all industries in the short term, with average output growth of 0.03%. Nevertheless, 36% of industries are hurt by rising labor prices, with output shrinking by an average of 0.02%. In the long run, output improves for 93% of industries, and the average output level is increased by a further 0.05% relative to the short run. This output growth is primarily due to the long-term improvement of EID quality, which reduces capital prices in most industries, thus bringing cost advantages to them. Nonetheless, output contracts in 10 sectors, falling by an average of 0.02%.

The output of industries can be divided into three categories according to the direction of change and the impact mechanism in the short and long terms. The first concerns industries that benefit both in

¹ Here, the increase of wastewater discharge does not consider other environmental regulation measures and is based only on the scenario hypothesis of this study. The actual agricultural wastewater discharge is regulated according to "one control, two reduction, and three basic" treatment measures in China.

Table 3

Comparison between regulatory effect of EID on wastewater emissions in the short and long term (unit: %).

		Short term			Long term			Short & Long term (difference)
		ET	ETID	ETID-ET	ET	ETID	ETID-ET	ETID-ET
COD	Total Emissions	-0.169	-0.169	0.001	-0.006	0.000	0.006	0.005
		(-4.293)	(-4.279)	(0.014)	(-0.147)	(0.003)	(0.150)	(0.136)
	Industrial Emissions	-0.169	-0.190	-0.020	-0.031	-0.035	-0.004	0.017
		(-2.745)	(-3.076)	(-0.331)	(-0.508)	(-0.569)	(-0.061)	(0.270)
	Household Emissions	-0.170	-0.132	0.038	0.039	0.063	0.023	-0.015
		(-1.548)	(-1.204)	(0.344)	(0.361)	(0.572)	(0.211)	(-0.133)
NH ₃	Total Emissions	-0.155	-0.145	0.010	0.013	0.025	0.012	0.002
		(-0.404)	(-0.379)	(0.025)	(0.035)	(0.067)	(0.032)	(0.006)
	Industrial Emissions	-0.136	-0.161	-0.025	-0.019	-0.021	-0.001	0.023
		(-0.159)	(-0.188)	(-0.029)	(-0.022)	(-0.024)	(-0.002)	(0.027)
	Household Emissions	-0.170	-0.132	0.038	0.039	0.063	0.023	-0.015
		(-0.245)	(-0.191)	(0.055)	(0.057)	(0.091)	(0.033)	(-0.021)

Note: Change in level value (unit: 10,000 tons) is shown in parentheses.

the short and long terms, particularly industries that produce investment goods and their main upstream sectors, as well as those for household and government consumption. The second concerns industries that suffer losses in the short term but gain in the long term, including capital-intensive energy industries and export-oriented industries. The third concerns industries that suffer losses in both short and long term, mainly coal and labor-intensive export-oriented industries.

4.3.1. Output of industries that benefit in both short and long term

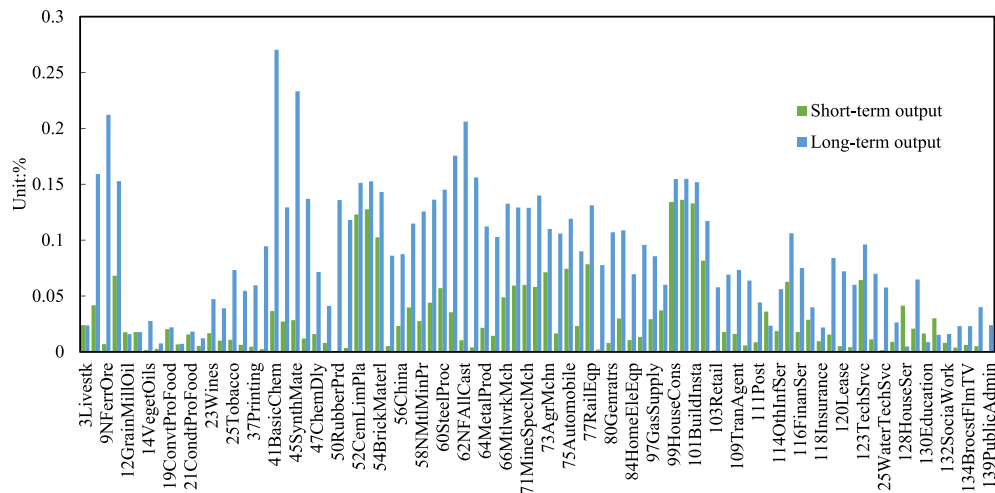
The output expansion in investment goods production industries and their upstream is driven by investment demand in the short term, while capital price decreases bring them cost advantages in the long term. This mainly involves the construction of buildings sector (99) and its upstream industries—the manufacture of basic chemicals (41), the manufacture of synthetic materials (45), the manufacture and casting of non-ferrous metals and related alloys (62), and other energy-intensive industries. The output of these sectors expands by 0.04% and 0.13% on average in the short and long term, respectively, making them the most profitable sectors. Taking the manufacture of basic chemicals sector (41) as an example, an improvement in EID quality stimulates investment demand in the short term, which boosts the output expansion of the construction of buildings sector (99) by 0.13% (98.9% of the products are used for investment demand), thereby increasing the demand for its upstream industry—the manufacture of basic chemicals (41) and other industries, which boosts its output growth by 0.04%. The improvement in EID reduces financing costs in the long term, decreasing the capital prices. Since the manufacture of basic chemicals sector (41) is capital-intensive, its output increases further by 0.23% in the short term

(see Fig. 3). The further expansion of output in these energy-intensive industries also brings an increase in pollutant emissions; thus, the EID's enhancing effect on environmental tax-driven pollutant emissions reduction in the long term is lower than that in the short term.

The output of the consumer goods production sectors benefit from the increase in household consumption demand in both short and long run. In addition, the increase in government expenditure boosts the output growth of government service sectors in the long term. The improvement in EID stimulates increased output in the consumer goods industries in the short and long terms, affecting the services to households sector (128), the production and distribution of water sector (98), the food and beverage services sector (113), the manufacture of milk and dairy products sector (20), and other industries primarily used for household consumption. The boost in consumer consumption will stimulate demand for these industries, and their output will expand further. Assuming that government spending is exogenous in the short term, the output growth in industries involved mainly in government consumption is minimal. However, government expenditure is strongly related to household consumption in the long term; hence, the increase in household consumption will increase government expenditure, causing growth in output among industries involved mainly in government consumption, such as those involved in the management of public facilities (127), health care (131), and education (130), which grow by 0.01% to 0.03% (see Fig. 3).

4.3.2. Output of industries that lose in the short term but gain in the long term

The output of most capital-intensive energy industries shrinks due to

**Fig. 3.** Output of industries that benefit in the short and long term.

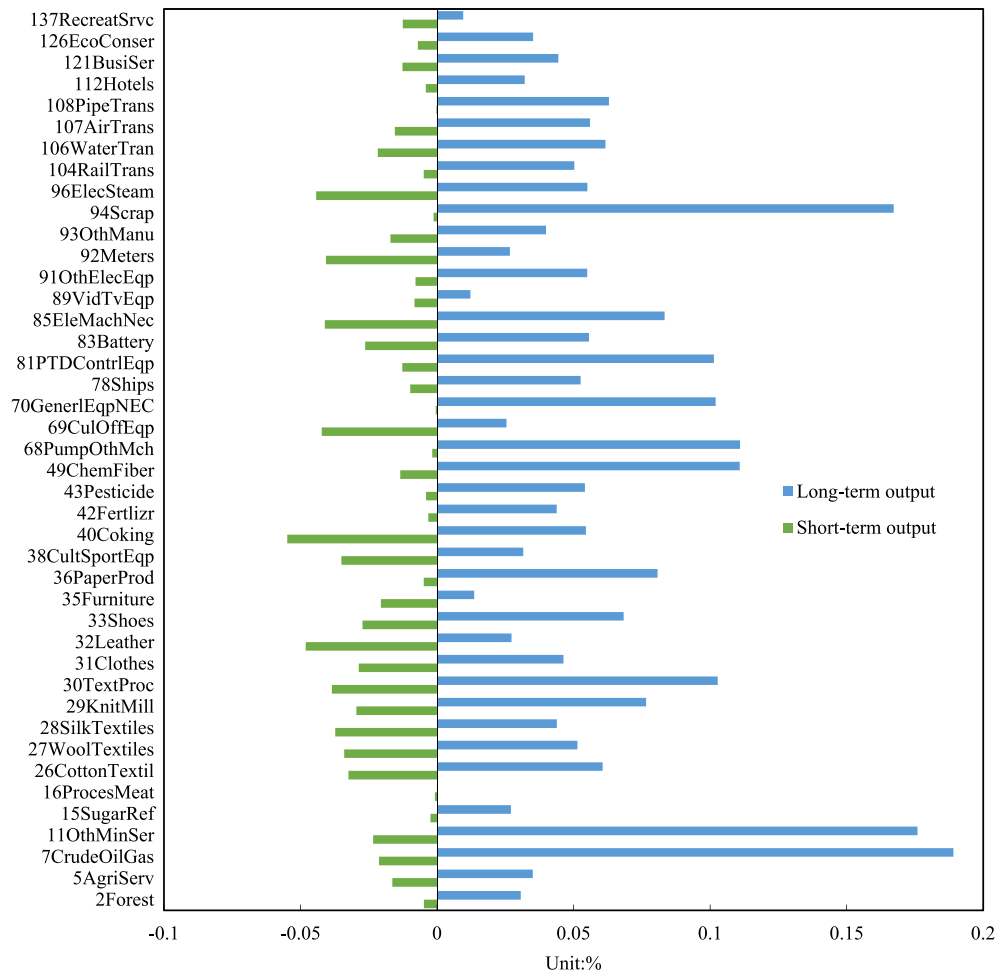


Fig. 4. Output of industries that lose in the short term but benefit in the long term.

the decrease in energy demand in the short term, whereas the decline in capital prices largely reverses the output damage in the long term. Specifically, improved EID promotes output expansion by stimulating investment in the short term, thus increasing the energy input. However, improving energy efficiency in heavy-polluting industries reduces energy demand. Due to the leading role of energy efficiency improvement in the short term, the total energy demand falls by 0.37%, which in turn leads to a 0.02%–0.05% contraction in the output scale of the energy sectors, such as the production and supply of electricity and steam (96). An improvement in EID reduces the financing cost of energy industries, resulting in a sharp drop in capital prices in the long term. Since sectors such as the production and supply of electricity and steam (96), the extraction of crude petroleum and natural gas (7), and the manufacture of coke products (40) are all capital-intensive, the lower capital prices boost their output by 0.05% to 0.19% (see Fig. 4).

The output of labor-intensive export-oriented industries is reduced by higher factor prices in the short term, while the output in most sectors is improved by lower capital prices in the long term. These industries include the manufacture of footwear (33), the manufacture of textile wearing apparel (31), and the manufacture of other electrical machinery and equipment (85). For instance, the manufacture of made-up textile articles sector (30) is labor-intensive, and 51% of the goods produced in this industry are exported. In the short term, an improvement in EID quality leads to an increase in the labor price, and the manufacture of made-up textile articles sector (30) and its main intermediate input industries such as spinning, weaving, and finishing of cotton and chemical

fibers (26) are also labor-intensive, which will lead to a cost increase for textile manufactured products and a reduction in export demand, as well as a 0.04% decline in output. However, improved EID quality in the long term reverses output losses in the manufacture of made-up textile articles sector (30) because the sharp reduction in the capital price is greater than the increase in the labor price, which substantially decreases production costs in this industry. Meanwhile, the demand for exports is also stimulated by the lower price, which ultimately expands the output by 0.1% (see Fig. 4).

4.3.3. Output of industries that lose in both short and long term

The energy demand reduction leads to a decline in output for the mining and washing of coal sector (6) in the short term, and the price substitution effect continues to decline in the long term, making this the most affected industry. In the short term, EID can encourage heavy-polluting industries to improve their energy efficiency and reduce their energy demand, which inhibits the expansion of output in the mining and washing of coal (6), and decreases its output by 0.12%. Influenced by long-term EID improvement, the capital price in the mining and washing of coal (6) also decreases, but its product prices decrease less than the product prices of other energy industries. Therefore, the substitution effect of price prompts energy consumption to switch from high-emission coal products to other relatively low-emission energy products, such as electricity and natural gas. In addition, energy efficiency in the downstream industries of the mining and washing of coal (6), such as the production and supply of electricity and

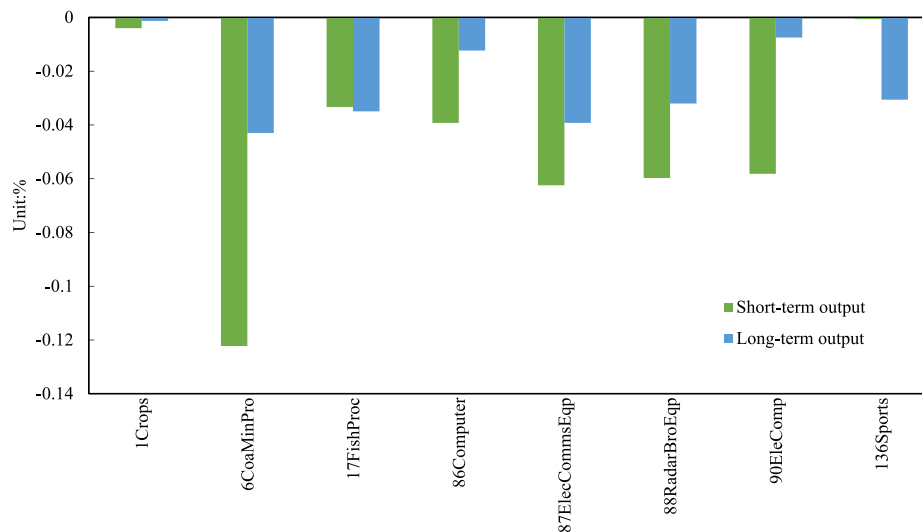


Fig. 5. Output of industries that lose in both short and long term.

steam sector (96), also improves by 0.1%, reducing the demand for coal mining products. Although the energy efficiency of the coal mining products industry also improves by 0.1%, the total reduction in coal demand in its downstream industries is greater than the output expansion caused by the improvement in energy efficiency, which results in a reduction of 0.04% in the output of the mining and washing of coal (6; see Fig. 5).

A few labor-intensive export-oriented industries, whose output decreases in the short term, continue to lose in the long term because of further increases in labor prices. For industries without EID improvements, such as the manufacture of computers (86), the manufacture of communication equipment (87), the manufacture of broadcasting, television equipment, radar and related equipment (88), the manufacture of electronic components and parts (90), and sports activities (136), the rising labor price increases the production cost of these industries in the short term, whereas the decline in capital prices is far lower than the increase in labor prices in the long term, causing a decline in exports and output shrinkage in these industries. The processing of aquatic products sector (17) belongs to the heavy-polluting industries that disclose environmental information. In the short term, EID improvement pushes up labor prices and decreases output by 0.03%. In the long term, improving the quality of EID lowers capital prices but increases the labor price, then increases prices in its upstream fishery industry (4). Hence, the intermediate input cost and product price of the processing of aquatic products sector (17) increase, inhibiting its exports and reduces output further by 0.01% (see Fig. 5).

5. Discussion and limitations

The purpose of this study is to investigate the regulatory effect of improvements in EID on both pollutant emissions reduction and economic growth in the context of environmental taxes using a CGE model. We find that EID as a “soft constraint” can achieve a “double dividend” effect compared to strict formal environmental regulations, but this effect displays significant temporal and industrial heterogeneities. The result of our survey on China is consistent with some previous studies on emerging economies, such as Mexico, the Philippines, Indonesia and India, documenting that EID can work to reduce pollution emissions and improve firms’ economic performances (Dasgupta et al., 2001; García et al., 2009; Powers et al., 2011). Khanna and Liao (2014) and Zhao (2019) also confirmed our results that EID could be a beneficial complement to traditional environmental regulations and thus be widely used in many developing countries. This study further discussed the temporal and industrial heterogeneities of this “double dividend” effect.

However, there are some scholars whose findings differ from ours. For example, Huang and Chen (2015) argued that the impact of EID on reducing emissions was limited and insignificant. The possible reasons for this discrepancy are that some listed companies they surveyed merely advertised their environmental responsibilities instead of reducing environmental risks, indicating that the law enforcement system must be improved in emerging economies.

Furthermore, some studies focus on the impact path of EID on emissions reduction and economic performance for firms using econometric models. The econometric approach is usually based on micro-data on pollutant emissions, competitiveness, and financing costs of heavy-polluting firms (Tian et al., 2016; Fonseca et al., 2019; Luo et al., 2019). The regression results obtained from these studies can provide data for shocks in the CGE model. Compared to econometric approaches, CGE models can identify the synergistic effect of environmental regulations, distinguish their direct and indirect impact paths on economic growth and emissions, and reveal the spillover feedback effects of these policies across industries (Choi et al., 2017; Li et al., 2019; Ojha et al., 2020). Therefore, studies based on a general equilibrium perspective can assess the general effect of environmental regulations on the macro-economy and total emissions, which is more conducive to policy-making. However, studies assessing the synergistic effects of environmental regulations using CGE models have mostly focused on the interactions between formal environmental regulations (Bi et al., 2019; Hu et al., 2021), with less attention paid to the synergies between informal and formal ones, especially the temporal and industrial heterogeneity of such effects. Tang et al. (2020) compared how policy regulations and carbon emissions trading could yield synergistic effects based on the perspective of firm heterogeneity. Nevertheless, the role of EID as a “soft constraint” in regulating the economic and environmental impacts of formal environmental regulations was not fully understood. Our findings that improvements in EID have a “double dividend” regulatory effect, which shows significant temporal and industrial heterogeneities, could provide policy implications for China to enhance and diversify its green growth approaches.

This study includes three major limitations that could be addressed in future studies: First, the cost of EID improvements was not considered. Disclosing environmental information forces firms to devote part of their productive resources to pollutant treatment, which will lead to increased production costs. Therefore, the regulatory compliance costs of EID improvements must be evaluated in future studies. Second, we only considered the scenario of EID improvements in heavy-polluting industries. However, the impact of other industries that voluntarily disclose their environmental information has not been considered; thus,

scenarios including expanded industry coverage should be designed in future studies. Third, improved EID is a positive “signal” that can lead to lower financing costs and higher share prices. In order to sustain this positive capital market feedback, in the long run, firms that disclose environmental information may spend the new capital on investing in green technologies to continuously improve their environmental performance instead of expanding production. This is a significant potential research direction.

6. Conclusions and policy implications

This study uses the Chinese environmental CGE model to reveal the regulatory effect and impact mechanism of EID improvement under environmental taxation in China. Our results show that EID improvement has a “double dividend” effect on pollutant emissions reduction and economic growth under environmental taxes, but the regulatory effect has obvious temporal heterogeneity. Specifically, the long-run economic stimulus effect of EID improvement (0.09% for GDP) is greater than the short-run effect (0.04% for GDP), whereas the EID’s long-run enhancing effect on exhaust gas emissions reduction (-0.02% for SO₂; -0.01% for NO_x) is lower than its short-run effect (-0.08% for SO₂; -0.08% for NO_x). Comparing the two regulatory effects, we find that the enhancing effect of EID on exhaust gas emissions reduction is greater than its enhancing effect on economic growth in the short run; however, in the long run, the effect on the former is weaker than its effect on the latter. In addition, the EID improvement has a weakening effect on wastewater discharge reduction, mainly due to the expansion in household consumption demand.

Improvements in EID can curb energy consumption in the short run by encouraging energy efficiency improvements and by promoting the transformation of energy demand from high-emission coal to other relatively cleaner alternatives in the long run, which helps change the energy consumption structure. Our results show that EID improvement can reduce pollutants and promote energy savings in the short run. Moreover, it can promote transformation in the energy structure and the low-carbon economy in the long run, confirming the “double dividend” effect of EID from the perspective of energy transformation.

The impact of EID improvement has obvious industrial heterogeneity. The output expansion in the investment goods production industry and its primary upstream industries is the most obvious, and output also increases in industries involved mainly in household and government consumption. Nevertheless, sectors that are upstream of investment-oriented industries, such as the manufacture of basic chemicals sector, are characterized by high energy consumption and high emissions, which means that improving EID will boost their output and pollutant emissions. A few labor-intensive and export-oriented industries, such as the processing of aquatic products sector, are damaged in the short run due to rising primary factor prices, and this is aggravated in the long run because of a further increase in labor prices. Based on these findings, this study proposes the following policy proposals:

- (1) Enterprises should be encouraged to disclose environmental information, and their responsibility as market entities in the environmental governance system should be strengthened. We find that EID has a positive regulatory effect of strengthening pollutant emissions reduction and stimulating economic growth under environmental taxes. Therefore, it is necessary to establish and improve the information disclosure systems of heavy-polluting enterprises, continuously improve the relevant regulations, and formulate standards for pollutant emissions and environmental monitoring. Specifically, the heavy-polluting firms should be urged to disclose important environmental information, such as pollutant names, discharge methods, and implementation standards, through their websites and other channels.
- (2) Long-run mechanisms for enterprises’ EID should be improved to adjust the economic impacts of formal environmental

regulations. The regulatory effects of EID differ between the short and long term. Its strengthening effect on pollutant emissions reduction is more significant in the short run, whereas its economic stimulus effect is more prominent in the long run. Therefore, improving the EID’s capacity to offset the economic cost of environmental taxation requires ensuring its continuous operation, urging action among heavy-polluting industries, maintaining integrity in environmental governance, and strengthening social supervision.

- (3) The content of enterprises’ EID should be refined to help promote the transformation of energy structures. Improvements in EID can drive energy consumption demand away from coal, with its high emissions, to other energy products with lower emissions through the relative change in energy prices. Therefore, the specific content of the energy consumption structure should become a part of the environmental information disclosed by enterprises, especially for firms that consume more coal products, to promote the transformation of the energy consumption structure.
- (4) Although the listed heavy-polluting firms in China are mandated to release their environmental reports, many firms may not be willing to disclose their information or take proactive environmental activities due to few penalties for non-compliance and high pollutant treatment costs. In order to increase firms’ motivation to disclose environmental information, market rating agencies should be encouraged to include mandatory disclosure of environmental information in the credit rating indexes of debt issuing firms, thus promoting more capital to flow to environmentally friendly firms and less to polluting ones. In addition, the government should provide financial supports such as sustained green subsidies and tax reduction for firms that undertake major environmental governance projects to reduce their environmental costs. The punishment for environmental violations should also be strengthened to efficiently monitor corporate environmental behaviors.
- (5) The household consumption sectors, in which EID improvement has an adverse regulatory effect on pollutant emissions reduction, should be regulated. The expansion of household demand also leads to increased pollutant emissions, weakening the pollutant emissions reduction effect of EID improvement. Therefore, effective measures, such as energy-saving stoves and clean energy substitution, should be taken to reduce coal combustion emissions. Simultaneously, household garbage needs to be comprehensively treated and recycled to reduce environmental pollution. It is noteworthy that the water fee paid by residents in China includes a sewage treatment fee, which can be increased in areas where households discharge more wastewater.
- (6) The labor-intensive and export-oriented industries that face shrinking output should be supported in the short run, while more attention should be paid to pollutant emissions reduction in energy-intensive industries in the long run. In the short run, most labor-intensive export-oriented industries suffer more severely due to higher factor prices, so supportive policies should be introduced to optimize their development. Improvements in EID also lead to pollutant emission increases in high energy-consuming industries, especially in the long run, due to a further expansion of output. Therefore, it is necessary to develop new energy-saving and emissions-reduction technologies and improve these industries’ energy efficiency and manufacturing techniques.

Our conclusions can also provide policy implications for other emerging economies. EID can be a pivotal informal environmental regulation that promotes green economic growth and environmental technology innovation in rapidly developing countries. Therefore, emerging economies should issue mandatory disclosure standards to unify the content, format and publication channels of environmental

information. In addition, formal environmental regulations such as environmental taxes must be improved to internalize the cost of emissions for firms. This would allow investors to access the environmental contingent liabilities faced by companies so that they can make the right investment decisions. Finally, EID should be used to promote green technology advances in developing countries. The heavy-polluting firms should be guided to disclose information on pollution control technologies. The trading platform for environmental technology should also be set up to accelerate technology transformation and reduce information asymmetry.

CRedit authorship contribution statement

Jin Zhu Zhang: Conceptualization, Software, Formal analysis, Writing – original draft, Writing – review & editing. **Yu Liu:** Conceptualization, Software, Methodology, Writing – review & editing. **Mei-fang Zhou:** Data curation, Formal analysis, Writing – review & editing. **Boyang Chen:** Investigation, Writing – review & editing. **Yawen Liu:** Writing – review & editing. **Baodong Cheng:** Writing – review & editing.

editing. **Jinjun Xue:** Writing – review & editing. **Wei Zhang:** Resources.

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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Appendix A. The environmental taxes of each province in China

Table A.1

The environmental taxes of each province in China (unit: yuan/pollutant equivalent)

Province (city)	Air pollutants (SO ₂ and NO _x)	Water pollutants (COD and NH ₃)	Province (city)	Air pollutants (SO ₂ and NO _x)	Water pollutants (COD and NH ₃)
Liaoning	1.2	1.4	Yunnan	2.8	3.5
Jilin	1.2	1.4	Jiangsu	4.8	5.6
Anhui	1.2	1.4	Hainan	2.4	2.8
Fujian	1.2	1.5	Sichuan	3.9	2.8
Jiangxi	1.2	1.4	Hebei	9.6	11.2
Shaanxi	1.2	1.4	Tianjin	6.0 (8.0)	7.5
Gansu	1.2	1.4	Beijing	12	14
Qinghai	1.2	1.4	Shandong	6	3
Ningxia	1.2	1.4	Shanghai	7.6 (8.8)	4.8 (1.4)
Xinjiang	1.2	1.4	Inner Mongolia	1.8	2.1
Zhejiang	1.2	1.4	Chongqing	2.4	3
Hubei	1.2	1.4	Tibet	1.2	1.4
Hunan	2.4	3	Henan	4.8	5.6
Guangdong	1.8	2.8	Shanxi	1.8	2.1
Heilongjiang	1.2	1.4			

The pollutant equivalents of SO₂, NO_x, NH₃ and COD are 0.95, 0.95, 0.8 and 1 kg, respectively.

Appendix B. Sector classification in 2012 input-output tables of China

Table B.1

Sector classification in 2012 input-output tables of China.

No.	Sector Classification	No.	Sector Classification
1	Farming	71	Manufacture of Machinery for Mining, Metallurgy and Construction
2	Forestry	72	Manufacture of Machinery for Chemical Industry, Timber and Nonmetal Processing
3	Animal Production	73	Manufacture of Machinery for Agriculture, Forestry, Animal Production and Fishery
4	Fishery	74	Manufacture of Other Special-Purpose Machinery
5	Support Services to Farming, Forestry, Animal Production and Fishery	75	Manufacture of Motor Vehicles, Except Parts and Accessories for Motor Vehicles
6	Mining and Washing of Coal★	76	Manufacture of Parts and Accessories for Motor Vehicles
7	Extraction of Crude Petroleum and Natural Gas★	77	Manufacture of Railway Transport Equipment
8	Mining of Ferrous Metal Ores★	78	Manufacture of Boats, Ships and Floating Devices
9	Mining of Non-Ferrous Metal Ores★	79	Manufacture of Other Transport Equipment
10	Mining and Quarrying of Nonmetallic Mineral★	80	Manufacture of Generators and Electric Motors
11	Mining Support Activities and Other Mining and Quarrying★	81	Manufacture of Equipment for Power Transmission and Distribution and Control
12	Manufacture of Grain Mill Products★	82	Manufacture of Wire, Cable, Optical Cable and Electrical Goods
13	Manufacture of Prepared Animal Feeds★	83	Manufacture of Batteries
14	Manufacture of Crude and Refined Oils from Vegetables★	84	Manufacture of Household Appliances
15	Manufacture of Sugar★	85	Manufacture of Other Electrical Machinery and Equipment
16	Slaughtering and Meat Processing★	86	Manufacture of Computers

(continued on next page)

Table B.1 (continued)

No.	Sector Classification	No.	Sector Classification
17	Processing of Aquatic Products★	87	Manufacture of Communication Equipment
18	Processing of Other Foods★	88	Manufacture of Broadcasting, Television Equipment, Radar and Related Equipment
19	Manufacture of Convenience Food Products★	89	Manufacture of Audiovisual Apparatus
20	Manufacture of Milk and Dairy Products★	90	Manufacture of Electronic Components and Parts
21	Manufacture of Flavoring and Ferment Products★	91	Manufacture of Other Electronic Equipment
22	Manufacture of Other Food Products★	92	Manufacture of Measuring Instruments and Meters
23	Manufacture of Alcohol and Alcoholic Beverages★	93	Other Manufacture
24	Manufacture of Soft Drinks and Refined Tea Products★	94	Comprehensive Utilization of Waste Resources
25	Manufacture of Tobacco Products★	95	Repair of Fabricated Metal Products, Machinery and Equipment
26	Spinning, Weaving and Finishing of Cotton and Chemical Fibers★	96	Production and Supply of Electricity and Steam★
27	Spinning, Weaving and Finishing of Wool★	97	Production and Distribution of Gas★
28	Spinning, Weaving and Finishing of Bast and Silk Fibers★	98	Production and Distribution of Water
29	Manufacture of Knitted and Crocheted Fabrics and Articles, Except Apparel★	99	Construction of Buildings★
30	Manufacture of Made-up Textile Articles, Except Apparel★	100	Civil Engineering★
31	Manufacture of Textile Wearing Apparel★	101	Construction Installation Activities★
32	Manufacture of Leather, Fur, Feather and Its Products★	102	Construction Completion and Finishing, Other Construction Activities★
33	Manufacture of Footwear★	103	Wholesale and Retail Trade
34	Processing of Timbers and Manufacture of Products of Wood, Bamboo, Rattan, Palm and Straw	104	Transport Via Railway
35	Manufacture of Furniture	105	Transport Via Road
36	Manufacture of Paper and Paper Products★	106	Water Transport
37	Printing and Reproduction of Recording Media★	107	Air Transport
38	Manufacture of Stationeries, Musical Instruments, Products of Arts and Crafts, Sports Goods, Games and Toys	108	Transport Via Pipeline
39	Manufacture of Refined Petroleum Products, Processing of Nuclear Fuel★	109	Cargo Handling, Transport Agency
40	Manufacture of Coke Products★	110	Storage
41	Manufacture of Basic Chemicals★	111	Post
42	Manufacture of Fertilizers★	112	Accommodation
43	Manufacture of Pesticides★	113	Food and Beverage Services
44	Manufacture of Paints, Printing Inks, Pigments and Similar Products★	114	Telecommunication and Other Information Transmission Services
45	Manufacture of Synthetic Materials★	115	Software and Information Technology Services
46	Manufacture of Special Chemical Products★	116	Monetary Intermediation and Other Financial Services
47	Manufacture of Daily-use Chemical Products★	117	Capital Market Services
48	Manufacture of Pharmaceutical Products★	118	Insurance
49	Manufacture of Chemical Fibers★	119	Real Estate
50	Manufacture of Rubber Products★	120	Renting and Leasing
51	Manufacture of Plastic Products★	121	Business Services
52	Manufacture of Nonmetallic Cement, Lime and Plaster★	122	Research and Experimental Development
53	Manufacture of Products of Plaster and Cement and Similar Products★	123	Professional Technique Services
54	Manufacture of Brick, Stone and Other Building Materials	124	Technique Promotion and Application Services
55	Manufacture of Glass and Glass Products	125	Management of Water Conservancy
56	Manufacture of Ceramic and Porcelain Products	126	Ecological Protection and Environmental Control
57	Manufacture of Refractory Products	127	Management of Public Facilities
58	Manufacture of Products of Graphite and Other Nonmetallic Minerals	128	Services to Households
59	Manufacture and Casting of Basic Iron and Steel★	129	Repair of Motor Vehicles, Electronic Products and Households Goods and Other Services
60	Processing of Steel Rolling Processing★	130	Education
61	Manufacture of Ferroalloy★	131	Health Care
62	Manufacture and Casting of Non-Ferrous Metals and Related Alloys★	132	Social Work Activities
63	Processing of Non-Ferrous Metals Rolling★	133	Journalism and Publishing
64	Manufacture of Fabricated Metal Products, Except Machinery and Equipment	134	Radio, Televisions, Movies and Audio-Video Recording Activities
65	Manufacture of Boiler and Prime Mover	135	Cultural, Art and Entertainment Activities
66	Manufacture of Metalworking Machinery	136	Sport Activities
67	Manufacture of Lifting and Handling Equipment	137	Amusement and Recreation Activities
68	Manufacture of Pump, Valve, Compressor and Similar Machinery	138	Social Security
69	Manufacture of Movie, Office Machinery and Equipment, of Projector and Camera	139	Public Management and Social Organization
70	Manufacture of Other General-Purpose Machinery		

The industries marked with an asterisk are 56 heavy-polluting industries shocked in the CGE model.

Appendix C. A BOTE analysis of EID's regulatory effect on macro-economy

The equilibrium of the economic module in the CGE model is shown in equations (C.1) to (C.12), and the meaning of each variable is presented in Table C1. Equation (C.1) represents GDP measured by the income approach, including the input of technology, capital, and labor. Equation (C.2) represents GDP measured by the expenditure approach, including household consumption, investment, government expenditure, and net exports. Equation (C.3) indicates that real wage depends on the marginal return of labor multiplied by technology and the reciprocal of and taxation. Equation (C.4) shows the determinants of the rate of return on investment. Equation (C.7) indicates that the real exchange rate is equal to the ratio of the import price to GDP price. Equation (C.8) shows that terms of trade are equal to the ratio of export prices to import prices. Equations (C.9) and (C.10) indicate that, in the short-run closure, investment depends on the rate of return on investment and financing costs, and household consumption is equal to the average propensity to consume multiplied by GDP. Equations (C.11) and (C.12) indicate that, in the long-run closure, investment and capital stock

change in the same proportion. Household and government consumption are fixed. In addition, exports are based on the big-country hypothesis that exports depend mainly on export prices, while imports are based on the small-country hypothesis that import prices are exogenous, and the real exchange rate is an important factor affecting net exports. (P_{GNE}/P_{GDP}) is the reciprocal of the terms of trade. (P_C/P_{GNE}) , (P_I/P_{GNE}) , and (P_{GDP}/P_F) are approximately equal to 1.

Table C.1
Meaning of variables in BOTE analysis.

variable	meaning	variable	meaning	variable	meaning
Y	GDP	T	tax	$\frac{P_{GNE}}{P_{GDP}}$	ratio of GNP price to GDP price
A	technology	$\frac{P_L}{P_C}$	real wage	$\frac{P_{GDP}}{P_F}$	ratio of GDP price to the weighted average price of primary factors
L	labor	$\frac{P_K}{P_I}$	rate of return on investment	FC	financing costs
K	capital	$F_L\left(\frac{K}{L}\right)$	marginal return on labor	APC	marginal propensity to consume
C	household consumption	$F_K\left(\frac{L}{K}\right)$	marginal return on capital	ER_r	real exchange rate (a rise means depreciation)
I	investment	$\frac{P_L}{P_F}$	real price of labor	P_M	import price
G	government consumption	$\frac{P_K}{P_F}$	real price of capital	P_X	export price
X	export	$\frac{P_C}{P_{GNE}}$	ratio of CPI to GNP price	P_{toft}	terms of trade
M	import	$\frac{P_I}{P_{GNE}}$	ratio of the price of investment goods to GNP price		

$$Y = A \cdot F(L, K) \quad (C.1)$$

$$Y = C + I + G + (X - M) \quad (C.2)$$

$$\frac{P_L}{P_C} = A \cdot \left(\frac{1}{T}\right) \cdot F_L\left(\frac{K}{L}\right) \quad (C.3)$$

$$\frac{P_K}{P_I} = A \cdot \left(\frac{1}{T}\right) \cdot F_K\left(\frac{L}{K}\right) \quad (C.4)$$

$$\frac{P_L}{P_F} = \frac{P_L}{P_C} \times \frac{P_C}{P_{GNE}} \times \frac{P_{GNE}}{P_{GDP}} \times \frac{P_{GDP}}{P_F} \quad (C.5)$$

$$\frac{P_K}{P_F} = \frac{P_K}{P_I} \times \frac{P_I}{P_{GNE}} \times \frac{P_{GNE}}{P_{GDP}} \times \frac{P_{GDP}}{P_F} \quad (C.6)$$

$$ER_r = \frac{P_M}{P_{GDP}} \quad (C.7)$$

$$P_{toft} = \frac{P_X}{P_M} \quad (C.8)$$

$$I = I\left(\frac{P_K}{P_I}, FC\right) \quad (C.9)$$

$$C = APC \cdot Y \quad (C.10)$$

$$\frac{I}{K} = R_I \quad (C.11)$$

$$\frac{C}{G} = R_C \quad (C.12)$$

Based on the above equations, the economic impact mechanism of EID improvement is analyzed in the short and long term, respectively. In the short term, improvements in EID quality encourage companies to promote technology (A) in equation (C.3). Assuming that the real wage (P_L/P_C) remains unchanged and that tax (T) is exogenous, the marginal return to labor (F_L) will decrease to keep equation (C.3) in balance. Capital stock (K) is fixed in the short run, so manufacturers can only increase the input of labor (L) to expand the total output (Y). Equation (C.4) shows that the increase in labor (L) input signifies that the marginal return of capital (F_K) and the rate of return on investment (P_K/P_I) both increase. In addition, an improvement in EID quality also reduces the financing cost (FC) in equation (C.9) and stimulates an increase in investment demand (I). From the expenditure side of GDP, the increase in total income (Y) will drive up demand for household consumption (C) and imports (M). Assuming that government expenditure (G) remains unchanged, net exports ($X-M$) will fall to maintain the balance of payments, which means that ER_r will fall (the real exchange rate appreciates). Assuming that the import price is exogenous, the GDP price will rise. The export price in equation (C.8) also increases because the export price and GDP price change in the same direction, indicating that the terms of trade P_{toft} are improved and export demand (X) decreases. The improvement in terms of trade signifies that (P_{GNE}/P_{GDP}) in equations (C.5) and (C.6) decreases, so the real price of labor (P_L/P_F) decreases. However, the increase in the return on investment (P_K/P_I) in equation (C.6) is greater than the decline in (P_{GNE}/P_{GDP}) , resulting in an increase in the real price of capital (P_K/P_F).

In the long run, improving EID's quality stimulates technological progress (A) in equation (C.4) and decreases the return on investment (P_K/P_I). Assuming that tax (T) is exogenous, the marginal return of capital (F_K) will fall. Since labor supply (L) remains unchanged in the long run, manufacturers can only increase the input of capital (K), thereby driving the growth of total output (Y). Equation (C.3) shows that, as the input of capital (K) continues to increase, the marginal return of labor (F_L) will rise, which in turn will increase real wages (P_L/P_C). From the expenditure side of GDP, investment (I) increases in the same proportion as capital stock (K). Concurrently, net exports (X-M) change in the same proportion as GDP, so net exports also increase. This means that the real exchange rate in equation (C.7) depreciates; thus, domestic products have a comparative advantage over imported products, leading to a decline in imports (M). Since the import price is exogenous, the GDP price in equation (C.7) decreases. It then follows that the export price in equation (C.8) also decreases, so the terms of trade will deteriorate, and export demand (X) will increase. This deterioration in terms of trade means that (P_{GNE}/P_{GDP}) in equations (C.5) and (C.6) increases, thereby raising the real price of labor (P_L/P_F). However, the decrease in return on investment (P_K/P_I) in equation (C.6) is greater than the increase in (P_{GNE}/P_{GDP}), resulting in a decrease in the real price of capital (P_K/P_F).

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